NIWA
Taihoro Nukurangi

Risks from Discharges from Exhaust Gas Cleaning - Scoping for Environmental Risk Assessment

Prepared for Ministry for the Environment

September 2020

Prepared by:
Jennifer Gadd

For any information regarding this report please contact:

Jennifer Gadd
Aquatic Chemist
Urban Aquatic Environments
+64-9-375 2058
jennifer.gadd@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
Private Bag 99940
Viaduct Harbour
Auckland 1010

Phone +64 9 375 2050

NIWA CLIENT REPORT No: 2018328AK
Report date: September 2020
NIWA Project: MFE20204

Quality Assurance Statement		
	Reviewed by:	Chris Hickey
	Formatting checked by:	Jennifer Gadd
	Approved for release by:	Jonathan Moores

Contents

Tables

Figures

Executive summary

The International Maritime Organization (IMO) convention on the Prevention of Marine Pollution (MARPOL) Annex VI: Regulations for the Prevention of Air Pollution from Ships came into effect in 2015 and limits the amount of sulfur permitted in fuel oil, to reduce the sulfur dioxide released into the air. One method to reduce sulfur dioxide emissions is to use an exhaust gas cleaning system (EGCS, also known as a scrubber). Most of the scrubbers in use operate by washing the exhaust gas with alkaline water, thereby generating an acidic washwater (from the sulfuric and sulphurous acids produced) containing elevated concentrations of particulates, nitrogen (from gaseous nitrogen oxides), hydrocarbons, and metals.

Discharges of the scrubber washwaters into marine waters represent a potential risk for marine environments. The Ministry for the Environment (MfE) engaged NIWA to assist in a risk assessment of the potential environmental effects from these scrubber discharges in New Zealand marine waters. This report represents Phase 1 of a two-stage process. The key objective of Phase 1 is to identify approaches that could be used to assess the environmental impacts of exhaust gas cleaning systems (scrubbers) in New Zealand. In Phase 2 the impact assessment will be undertaken, following one of the approaches identified in Phase 1. This report on Phase 1 reviews information on the scrubber washwaters, risk assessments undertaken overseas and sets out options for undertaking an environmental risk assessment for New Zealand.

Contaminant concentrations are highest in closed-loop scrubbers, where the washwater is recycled multiple times before being discharged, but discharge rates are much higher for open-loop systems where the washwater is continuously discharged in a one-pass through system. Discharges of washwater from either system therefore present a hazard in relation to changes in pH, increased turbidity, increased nitrogen, toxicity due to metals and hydrocarbons (particularly PAHs). There is also potential for increased concentrations of metals and PAHs in sediment and in biota, and thereby a route to human exposure through consumption of shellfish and fish.

The likely effects from these discharges are highly dependent on the number of ships using scrubbers in each location of interest, as well as on the engine power and loading rate, which affects the discharge quality and rate (higher contaminant concentrations and higher discharge rates with higher engine loading). Dilution and dispersion of the discharges is expected to be high when vessels are at sea but much lower within harbours and ports.

Some locations may have higher potential risk from the scrubber discharges, for example locations with high daily shipping numbers, low hydrodynamic flushing, sensitive ecological areas and areas of importance for fishing (including commercial and recreational; shellfish and finfish). These locations will need to be further identified in Phase 2, together with the information gathered from Mātauranga Māori perspectives.

There have been several hazard and risk assessments undertaken overseas regarding the discharges of scrubber washwaters, with mixed conclusions. Effects in shipping lanes and coastal waters have generally been predicted to be low; however effects in ports and harbours remain an area of uncertainty and potential concern due to the lower dispersion of contaminants and the higher background concentrations of contaminants from other sources.

The approach for a New Zealand risk assessment is presented with up to three options for each aspects of the assessment. These differ in complexity from simple, screening level information to those requiring more detailed data and modelling. The simple methods, whilst requiring lower resources are expected to have higher uncertainty than more detailed options.

1 Introduction

1.1 Background

Most ship engines in use around the world use fuel oil to generate power through internal combustion (electric engines remain uncommon). Combustion of that fuel oil results in the production of sulfur oxides (SO_2 and SO_3, collectively known as SO_X), with the amount produced related to the amount of sulfur in the fuel oil. Sulfur oxides can affect human health by harming respiratory systems, affect visibility, causing haze and contribute to acid rain. The International Maritime Organization (IMO) convention on the Prevention of Marine Pollution (MARPOL) Annex VI: Regulations for the Prevention of Air Pollution from Ships came into effect in 2015 and this limits the amount of sulfur permitted in fuel oil, to reduce the sulfur dioxide released into the air. Although some fuel oils available for use in ship engines have low sulfur content (0.5% or less) and therefore low releases of SO_x, other fuel oils have higher sulfur content (3.5%). To comply with the regulations, ships need to either a) change to low sulfur fuel oils (which may be at a premium price); b) change to alternative fuels such as liquefied natural gas (LNG); or c) remove the SO_x from the exhaust gases using an exhaust gas cleaning system (EGCS, also known as a scrubber[1]).

As New Zealand is not currently a signatory to MARPOL Annex VI, there are no requirements for New Zealand vessels to adhere to Annex VI low sulphur requirements when in New Zealand waters. However, there may be vessels visiting New Zealand waters that are registered to nations that are signatory to the Annex VI; or New Zealand registered vessels that travel to and from other states that are signatories to Annex VI (e.g., when visiting Australia for dry dock purposes) and have selected to have scrubbers installed as a method of compliance with those regulations. In 2017 to 2019, New Zealand had approximately 2500 ship visits each year, most of which were container vessels and bulk carriers, followed by tankers and vehicle carriers (Figure 1-1, Table 1-1). According to industry reports, as at January 2020 there were 3,756 vessels world-wide with scrubbers installed (Saraogi 2020). Almost all vessels visiting New Zealand in 2019 were registered to nations that are signatories to Annex VI (unpublished Customs data), so the vessels will be either using scrubbers or have converted to a low sulfur emissions fuel.

[1] There are also treatment systems that remove other gases from exhaust gases, including nitrogen oxides (NOx) using selective catalytic reduction. These are not in common use (Gregory 2012) and are not within the scope of this report.

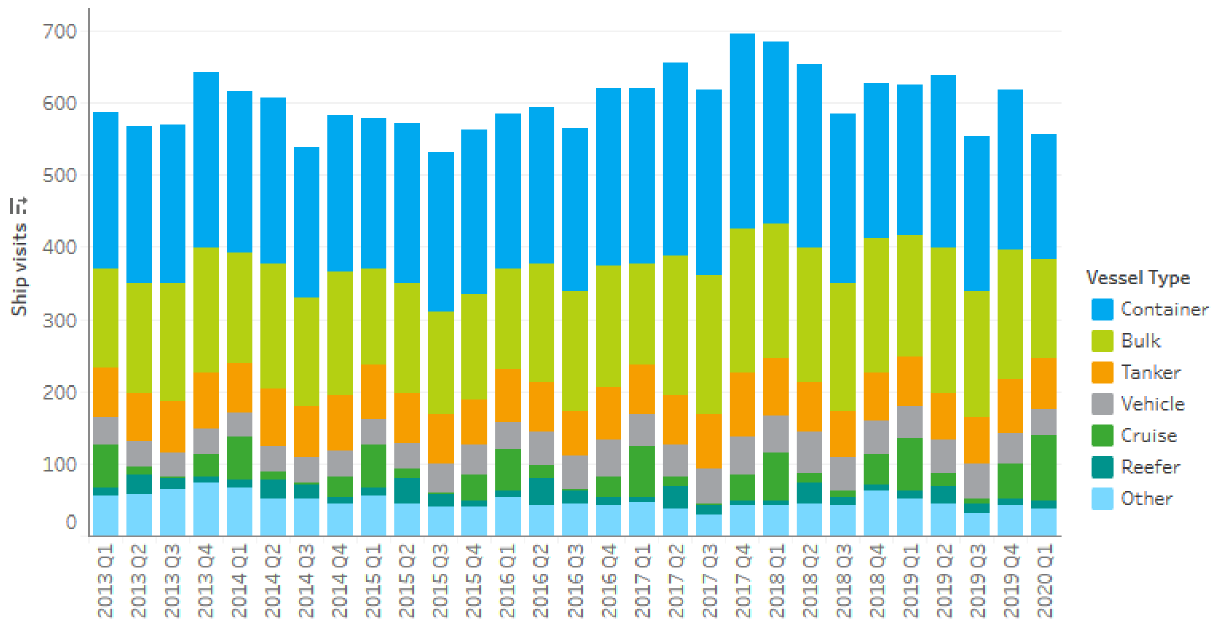


Figure 1-1: Overseas ship visits to New Zealand each quarter categorised by vessel type. From Stats NZ / https://www.transport.govt.nz/mot-resources/freight-resources/figs/overseas-ship-visits/

Table 1-1: Overseas ship arrivals to New Zealand ports.

Vessel type	Total in 2017	Total in 2018	Total in 2019	Average for 2017-2019	% each type
Container	1038	954	882	958	38%
Bulk	725	737	722	728	29%
Tanker	302	278	274	285	11%
Vehicle	189	203	181	191	8%
Cruise	124	133	146	134	5%
Reefer	58	53	56	56	2%
Other	154	190	171	172	7%
Total	2590	2548	2432	2523	

Most scrubber systems in use on ships work by spraying the exhaust gas with alkaline seawater, which dissolves the SO_x, removing >98% from the gas. This process also removes particulate matter and heavy metals that were also in the exhaust gas. The washwater created then contains particulates, metals and sulfur, as well as being acidic, with pH regularly <6 and therefore the discharges from the system have potential to affect the marine waters and ecosystems into which they are discharged (Table 1-2). Potential effects include effects from acidified waters, toxic effects from heavy metals and hydrocarbons and increased eutrophication from nitrogenous compounds (i.e., dissolved oxides of nitrogen, NOx). As vessels will be using scrubbers in New Zealand waters, there is potential for adverse effects on New Zealand coastal and estuarine (ports and harbours) environments from the discharge of the washwaters.

Table 1-2: Contaminants of potential concern to be considered in this risk assessment.

Stressor / contaminant	Source	Issue
Low pH	Dissolution of SOx and NOx	Direct effects on biota and indirect effects through changes to speciation of trace elements increasing or decreasing bioavailability
Nitrogenous compounds	Dissolution of NOx	A key nutrient for primary producers, can contribute to eutrophication
Turbidity / suspended solids	From the soot produced by incomplete combustion	Reduced clarity of water with aesthetic effects; effects on filter feeding organisms
Metals including toxic metals	Found in the heavy fuel oil (HFO) and released from within the engine or exhaust systems	Do not degrade, potentially toxic to marine biota, accumulate in sediment, some accumulate in biota
PAHs	Polycyclic aromatic hydrocarbons, found in heavy fuel oils and produced during incomplete combustion.	Degrade very slowly, potentially toxic to marine biota, hydrophobic and accumulate in sediment and biota. Some PAHs are carcinogenic and others are photoactive (i.e., enhanced toxicity when exposed to sunlight)
Other hydrocarbons including BTEX	From the heavy fuel oils	Potentially toxic to marine biota, some may be hydrophobic and accumulate in sediment and biota

1.2 Scope of this report

The Ministry for the Environment (MfE) engaged NIWA to assist in a risk assessment of the potential environmental effects from these scrubber discharges in New Zealand marine waters. This report represents Phase 1 of a two-stage process. The key objective of Phase 1 is to identify approaches that could be used to assess the environmental impacts of exhaust gas cleaning systems (scrubbers) in New Zealand.

This includes a literature review, that identifies the known environmental impacts of scrubber use (and current gaps in knowledge) and risk assessment approaches followed in other jurisdictions. This phase also sets out options for a risk assessment framework, with the options varying based on considerations such as data availability, cost, and spatial coverage. All recommended options must assist MfE in assessing whether regulatory intervention is required for scrubbers in New Zealand.

Phase 2 of this process will be to undertake a risk assessment, based on one of the options outlined in this Phase 1 report.

1.3 Overview of risk assessment and this report

Generally, environmental risk assessments follow a multi-step tiered process, such as that set out in Figure 1-2, which includes:

- **Planning and problem formulation** to define the purpose, scope, objectives and approach of the assessment.
- **Hazard identification**, where the possible contaminants of concern are identified, potential receptors are identified, and the type and nature of adverse environmental effects are identified.
- **Hazard characterisation** (toxicity assessment in NZ terminology), examines the types of adverse effects that the contaminants of concern cause, and the concentrations that cause these effects, using dose-response factors, based on laboratory or field-based studies.
- **Exposure assessment** examines what the concentrations of the contaminants are in the environment, the routes of exposure to the receptors, and the frequency, timing, and levels of contact with the environmental media, to determine the contact with the contaminants of concern.
- **Risk characterisation** combines the toxicity (including native species of high concern, food-chain accumulation – including effects on humans) and exposure assessments to determine the probability of an effect from contaminants, either individually or in combination.

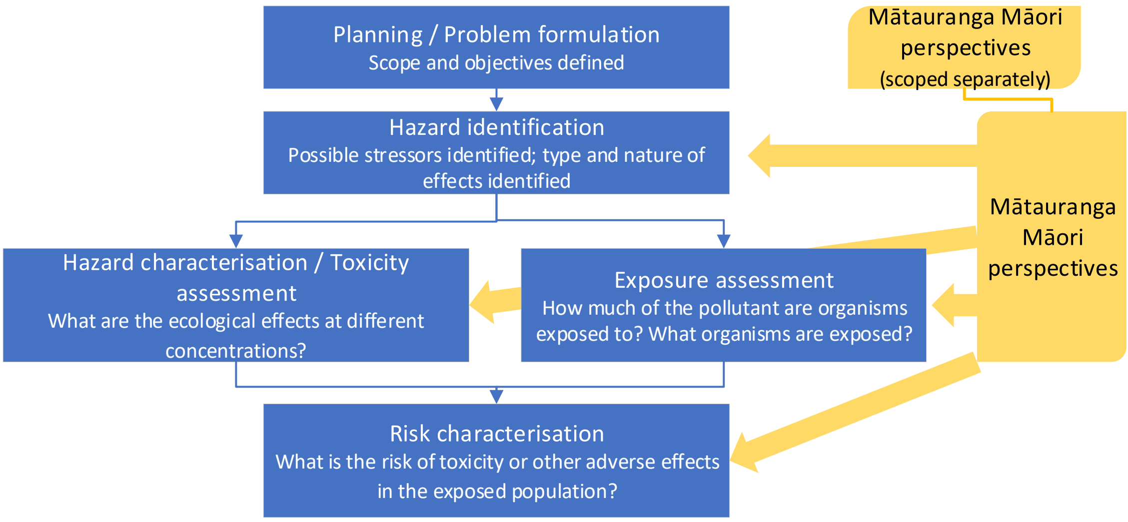


Figure 1-2: Generic framework for ecological risk assessment. Adapted from US EPA (2019a) and IPCS (2010).

Mātauranga Māori perspectives and values can feed into the risk assessment process at various stages, including in identifying types of effects that may be of particular interest (e.g., effects on suitability of food for consumption), locations of particular interest, identifying marine organisms of importance and setting levels of risk that are acceptable. These perspectives are not in scope for this review but are being gathered in a separate process undertaken by MfE which includes mapping of regions and iwi groups that are potentially impacted by the scrubber discharges. The way these perspectives are input into the risk assessment process will be considered during Phase 2.

Risk assessments are often considered as tiered approaches: a Tier 1 assessment would use default values, aiming to be conservative and act as a screening level risk assessment. In many cases only a screening level assessment is required to identify the absence of risk for potential effects. However, if risks are identified during screening level assessments, then higher tier assessments may be required. For higher tier risk assessments, more data are acquired and more sophisticated models are used to provide more accurate representations of reality. Higher tier risk assessments may also be more site-specific, i.e., to a particular location of interest.

This report covers the planning and problem formulation and the hazard identification steps of the risk assessment (steps 1 and 2), and collates information that can be used in the other steps of the risk assessment for use during Phase 2. This report covers the following items:

- An overview of scrubber systems, including the chemistry and different scrubber types;
- A review of literature and risk (or hazard) assessments conducted overseas;
- The contaminants of potential concern in scrubber discharges and the hazards they pose;
- The information that would be required to assess exposure to scrubber washwater discharges;
- Locations in New Zealand that may be particularly sensitive, either due to the high number of vessels or the organisms present there, together with potential food-chain exposure pathways (particularly to humans);
- Options for conducting a quantitative risk assessment of scrubber washwater discharges in New Zealand.

2 Scrubber systems

2.1 Chemistry of scrubber systems

Most of the exhaust gas cleaning systems on ships are wet scrubbers, which work by spraying the exhaust gas with water, to dissolve the SO_x (inset Box 2-1). As this results in the production of sulfuric and sulfurous acids, the washwater must either have natural buffering capacity (such as alkaline seawater, pH ~8.2), or, in the case of freshwater, alkaline substances such as NaOH (also known as caustic soda) must be added to provide this buffering.

Box 2-1: Chemistry of reactions in exhaust gases and in scrubbers.

Combustion:	$S + O_2 \rightarrow SO_2$ $SO_2 + {}^1/_2\, O_2 \rightarrow SO_3$	
Reactions in a scrubber:	$SO_2 + H_2O \rightarrow H_2SO_3 \rightarrow 2H^+ + {SO_3}^{2-}$ $SO_3 + H_2O \rightarrow H_2SO_4 \rightarrow 2H^+ + {SO_4}^{2-}$	*(sulphurous acid)* *(sulphuric acid)*
	$NO + O_2 + H_2O \rightarrow HNO_2 \rightarrow H^+ + {NO_3}^- + NO$	*(nitrous acid, which decomposes)*
	$NO_2 + H_2O \rightarrow HNO_3 + HNO_2 \rightarrow H^+ + {NO_3}^- + NO$	*(nitric + nitrous acid)*
Neutralisation with alkaline seawater:	${CO_3}^{2-} + H_2SO_3 \rightarrow HCO_3^- + {SO_3}^{2-}$ ${HCO_3}^- + H_2SO_3 \rightarrow H_2O + CO_2 + {SO_3}^{2-}$	*(carbonate & bicarbonate provide buffering)*
Neutralisation with NaOH in freshwater scrubbers:	$NaOH + H_2SO_3 \rightarrow H_2O + Na^+ + {SO_3}^{2-}$	

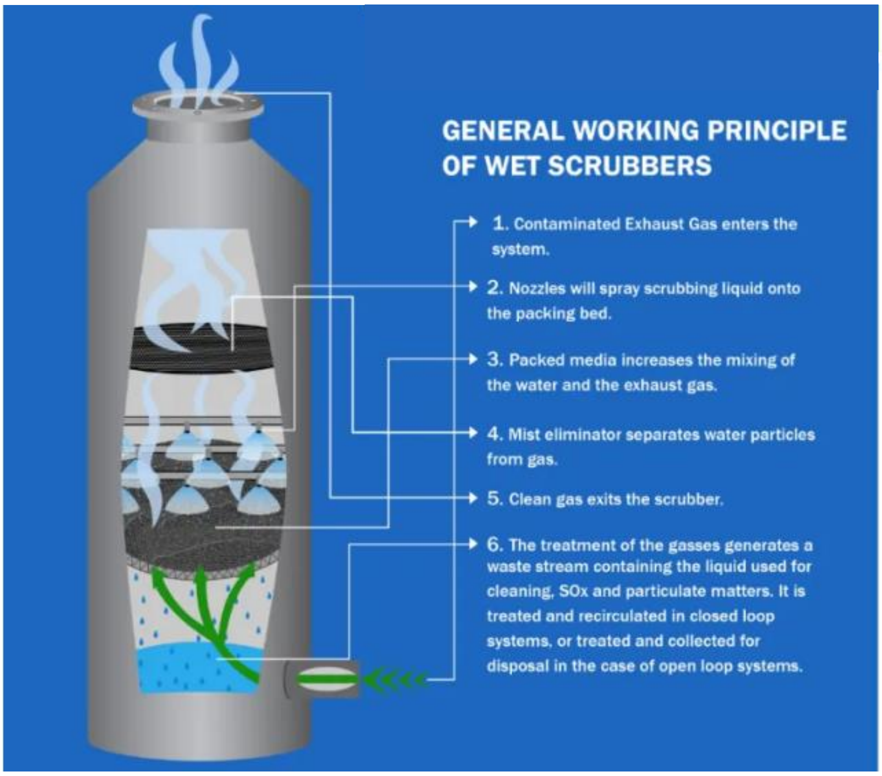


Figure 2-1: Diagram of working principle of wet scrubbers. From (World Maritime Affairs 2019)

2.2 Scrubber types

Wet scrubbers come in three types: open loop, closed loop and hybrid systems, which are a combination of the first two.

Open loop scrubber systems are the simplest and use sea water as the scrubbing water, taking advantage of its natural alkalinity and buffering capacity to neutralise the acidity of the washwater. Water is pumped from the sea into the scrubber, then discharged back into the sea (Figure 2-2). In some cases, there is a cleaning unit to remove particulate matter (retained as sludge) prior to discharge. The discharge rates from open-loop scrubbers depends on the engine power at the time of operation, and to a lesser extent, the particular scrubber installed. There is reasonable agreement that the discharge rate from open loop scrubbers is around 20-50 m^3/hr/MW or 6-14 L/s/MW.

Closed-loop systems (Figure 2-2) use a dedicated water supply (usually freshwater) which is used in the scrubber then recirculated and reused multiple times. Alkaline substances (usually NaOH) are added to the water to buffer against the acidic washes. The recirculating water needs to be gradually exchanged with clean water, and the dirty water is removed from the system at a low but relatively constant rate as ”bleed-off”. This “bleed-off” is then treated and can either be discharged at sea or held in a storage tank for later disposal either at sea or on land. As such, closed-loop systems have a much lower rate of discharge than open-loop systems, estimated at 0.1-0.3 m^3/hr/MW. However, because the water is recirculated multiple times (unlike the open-loop systems), the discharge contains higher contaminant concentrations than discharges from open-loop systems. Closed loop systems are particularly used for ships operating in freshwater environments (e.g., the Great Lakes of North America) as the intake water would not have sufficient alkalinity to neutralise the acids produced before discharge.

A hybrid system usually incorporates both open and closed- loop systems (Figure 2-2). This enables use of the open loop mode when at sea and closed-loop mode when in port or in zones where emissions are banned.

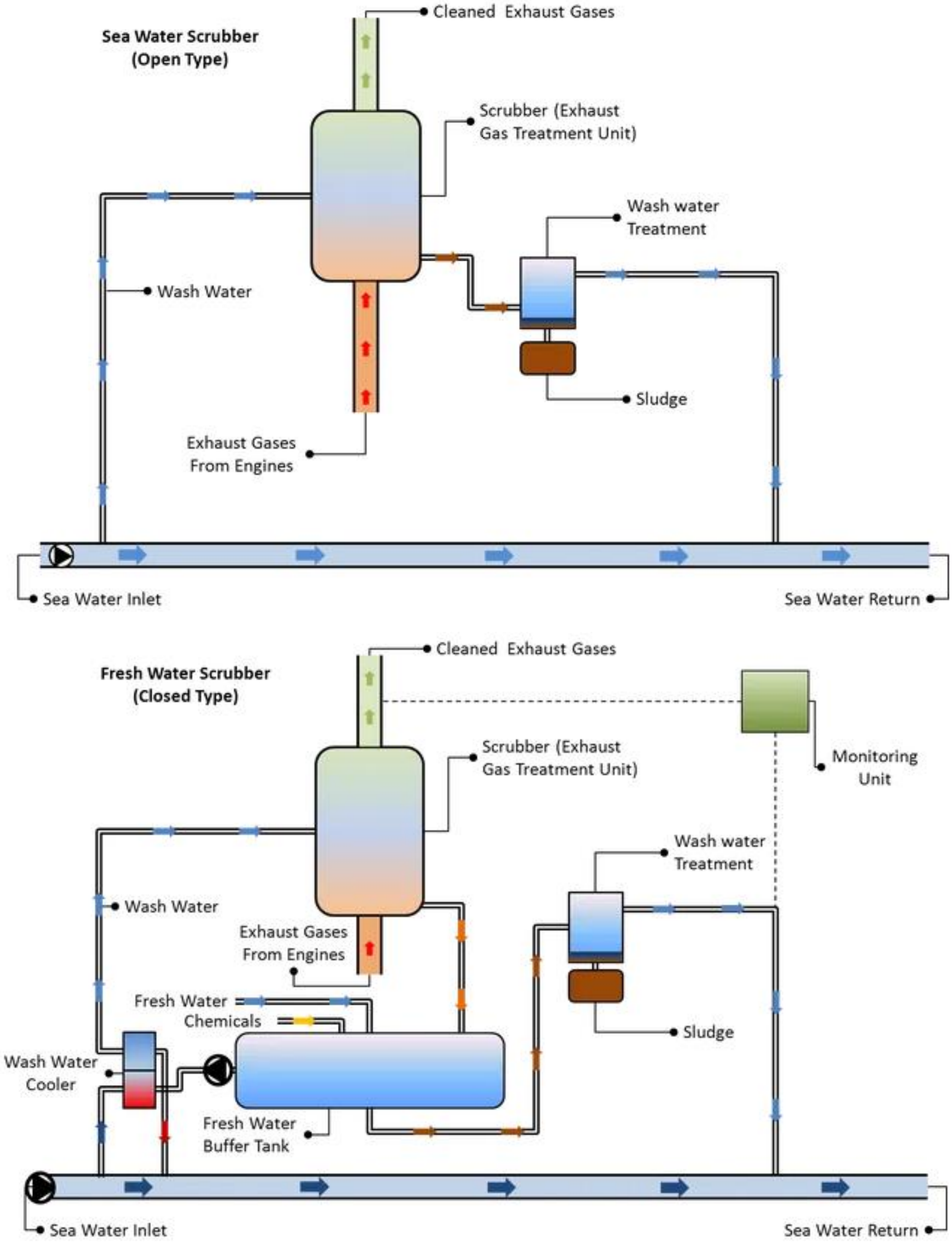


Figure 2-2: Scrubber types: Open-loop (top); closed-loop (bottom). Figure from Gregory (2012).

2.3 Scrubber installation options

Most ships have one or more main engines, and may have auxiliary engines (e.g., bow and thrust engines) as well as generators to produce electricity for use on the ship. Scrubbers can be installed as separate items on each engine, or a combined system can be used (Figure 2-3).

The scrubber configuration has implications for the volumes of washwater generated. The greater the power generation, the more washwater is generated and discharged, particularly with open-loop scrubbers. Furthermore, if scrubbers are only attached to the main engines, and these engines are not in use when the vessel is docked, then the scrubber will not be in use or discharging when the vessel is in dock.

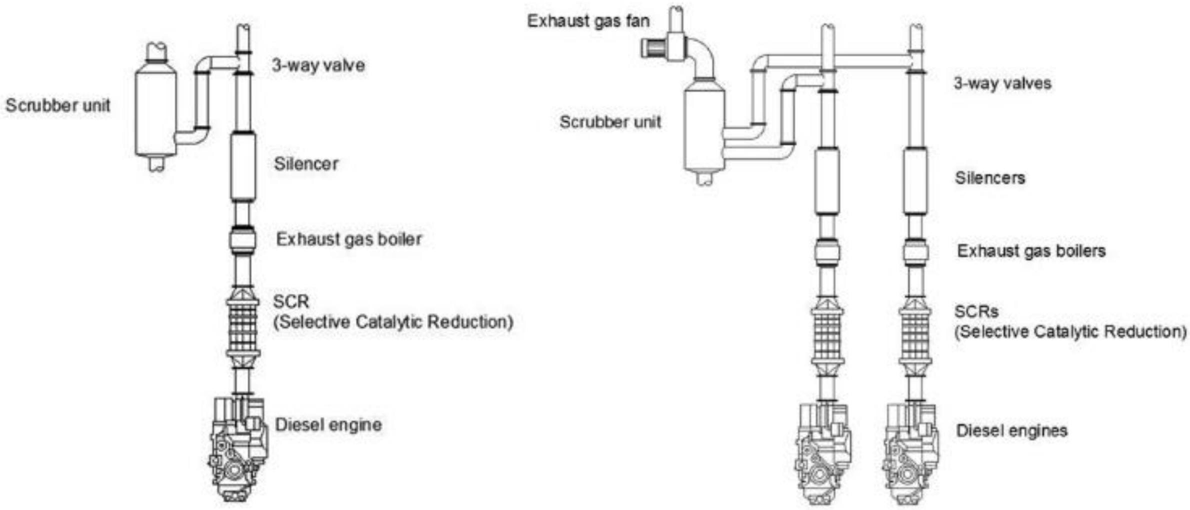


Figure 2-3: Installation options for scrubbers, either on a single engine (left) or combined engines (right). Figure from (Wärtisilä 2014).

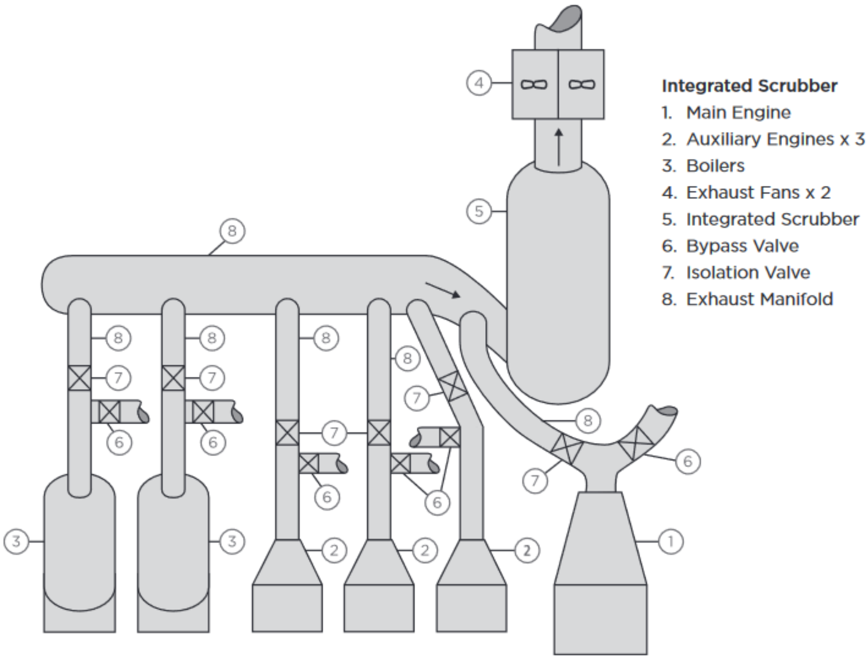


Figure 2-4: Diagram indicating a combined installation option where scrubber is attached to the main engine and multiple auxiliary engines. Figure from (ABS 2017).

2.4 Scrubber discharge guidelines

The IMO sets guidelines for the use of exhaust gas cleaning systems, including criteria around the quality of the washwater discharges (IMO Secretariat 2015). The guidelines require the washwater is continuously monitored for pH, PAHs, turbidity and temperature when the system is in operation in ports, harbours or estuaries (but not in other coastal or marine waters). The guidelines require that:

- pH is no less than 6.5 as measured at the overboard discharge, or achieve a minimum pH 6.5 at 4 m from the discharge point when the ship is stationary, as determined either by measurement or calculation.
- The maximum continuous PAH concentration in the washwater should not be greater than 50 µg/L PAH_{phe} (phenanthrene equivalence) above the inlet water PAH concentration as measured after water treatment but before any dilution. This limit is based on a discharge rate of 45 m^3/MW/hr and can be adjusted upwards for lower flow rates.
- The maximum continuous turbidity should be less than 25 FNU (formazin nephlometric units) or NTU (nephlometric turbidity units) above the inlet water turbidity; as measured as a rolling average over a 15-minute period. For a 15-minute period in any 12-hour period, the limit may be exceeded by 20%.
- The washwater treatment system should prevent the discharge of nitrates that associated with a 12% removal of NO_X from the exhaust, or beyond 60 mg/L (normalized for washwater discharge rate of 45 tons/MWh), whichever is greater.
- Washwater residues (e.g., solids produced after treatment through settling) should not be discharged to sea or incinerated on board and should be disposed of onshore at suitable facilities.

These guidelines are not currently mandatory, but industry operators expect that they could become mandatory in the future[2].

2.5 Discharge rates and volumes

The rate of the scrubber washwater discharge depends on the following factors:

- The type of scrubber and its operation mode (open-loop vs closed loop),
- The size of the engines the scrubber is connected to, and
- The current engine load of the vessel (i.e., how much power the engine is generating at the time, which relates mainly to the vessel speed).

Discharge rates are usually estimated on the basis of engine power and although there is a range in the estimates from each manufacturer (**Error! Reference source not found.**), there is reasonable agreement that the discharge rate from open loop scrubbers is around 20-50 m^3/hr/MW or 6-14 L/s/MW. Closed-loop systems have much lower discharge rates with bleed-off rates estimated at 0.1-0.3 m^3/hr/MW, however as there are storage tanks in these systems, there can be no discharge at all for short periods.

[2] https://www.seatrade-maritime.com/europe/mandatory-monitoring-scrubber-washwater-inevitable-rivertrace

Table 2-1: Industry estimates of discharge rates from open-loop scrubbers. Source: Gregory (2012).

Scrubber manufacturer	Estimated open-loop discharge rate (m^3/hr/MW engine power) [1]	Discharge rate from vessel with 20 MW engines (m^3/hr) [2]
Alfa Laval	50	1000
Clean Marine	20 – 40	400 – 800
Wärtisilä / Hamworthy	45	900
Marine Exhaust Solutions	50	1000

Note: [1] based on 100% engine load. [2] Equivalent to a large RoRo/RoPax vessel.

3 Contaminants of potential concern in scrubber discharges

3.1 Introduction

Contaminants will be found in the washwater from four sources: the seawater or freshwater used as washwater, any chemical additives used, exhaust gas exiting the engine (air, fuel, lubricant and combustion products), and wear and tear of the scrubber itself. There have been numerous studies of the quality of the washwater discharges, starting from investigations of washwater from prototype scrubbers in 2005 / 06 (Buhaug et al. 2006, Hufnagl et al. 2005, Niemi et al. 2006, US EPA 2011, Wärtisilä 2010). These studies have investigated the discharges from scrubbers installed on a variety of vessels including ferries, cruise liners, container vessels and tankers (see Table 3-1).

The majority of the studies have focussed on:

- pH (due to the acidity produced as the SOx dissolves in water, see section 2.1)
- particulate matter or turbidity, from the carbon produced during combustion
- Chemical Oxygen Demand (COD) as an indicator of oxygen demand
- Nitrate from the dissolution of NOx
- metals associated with the fuels (especially vanadium and nickel) and to a lesser extent from lubricating oil, wear of the engine and the scrubber system
- hydrocarbons including PAHs produced during incomplete combustion.

Table 3-1: Studies investigating the quality of scrubber washwater discharges.

Ship name	Year of study	Ship type	Scrubber type	Reference
MV Fjordshell	1993	Oil tanker	Prototype	Buhaug et al. (2006)
Pride of Kent	2004	RoRo/RoPax	Open-loop	Hufnagl et al. (2005); US EPA (2011)
MS Zaandam	2007-08	Cruise	Open-loop	HA & H-K (2010), cited in US EPA (2011)
MT Suula	2008	Chemical tanker	Closed-loop (freshwater)	Wärtisilä (2010) USEPA (2011)
MV Ficaria Seaways	2011	RoRo/RoPax	Hybrid scrubber, open-loop (seawater) & closed loop (freshwater)	Kjølholt et al. (2012); Hansen (2012)
22 vessels, names anonymised	2015-2017	11 RoRo/RoPax; 3 cruise, 3 oil tanker, 2 vehicle carriers, 1 each of RoRo container, container and multi-purpose	16 hybrids, 5 open-loop and 1 closed-loop system	EGCSA and Euroshore (2018)
MV Magnolia Seaways	2016	Bulk carrier	Open-loop scrubber	Koski et al. (2017)
Unnamed	2017	Panamax bulk carrier	Hybrid operating in open-loop mode	Koyama et al. (2018)
Stena Britannica Stena Transporter Stena Forerunner	2017/18 [a]	RoPax RoRo cargo RoRo cargo	closed-loop closed-loop open-loop	Magnusson et al. (2018)
5 ships, not named	2017/18 [a]	Not reported	4 hybrids, operating in either closed-loop or open-loop mode; 1 open-loop	BSH (2018)

Note: [a] Not specified in report, date estimated based on publication date.

In most studies washwater samples have typically been collected at the point of discharge, and many have included samples of the seawater prior to the scrubber. Several studies have also undertaken toxicity testing, with one or more marine species to assess effects on growth, reproduction and/or mortality (Hufnagl et al. 2005, Koski et al. 2017, Koyama et al. 2018, Magnusson et al. 2018, Ytreberg et al. 2019).

Key findings from the analyses of washwater discharges are presented in this section, and comprehensive database of the test results is available as an excel file, with a subset of this tabulated in Appendix A.

3.2 pH

The pH of the washwater is low, as sulfuric acid is produced during the scrubber process and it varies from <3 to nearly 8, depending on the scrubber mode, engine size and power output (Figure 3-1), with lowest pH during high engine load (Appendix A). The pH is closer to neutral in the closed-loop mode as alkaline substances are used to neutralise the sulfuric acid, whereas in open-loop mode, the natural alkalinity of seawater is relied on for buffering. Although pH depends somewhat on the initial pH of the intake water, seawater has a near-constant pH and alkalinity world-wide (pH 8.2, alkalinity ~116 mg/L), with the exception of specific locations such as the Baltic Sea and in locations around river mouths and other freshwater sources. There are also locations around New Zealand where the pH is somewhat lower (for example, parts of the Hauraki Gulf) and this will need to be considered in Phase 2.

Figure 3-1: Discharge washwater pH for scrubbers operating in open-loop or closed-loop mode. From data collated in Appendix A.

3.3 Suspended solids and clarity

The washwaters can contain suspended solids, as particles (including soot) are scrubbed from the exhaust gases. Measurements of the washwaters suggest concentrations of suspended solids are relatively low, generally less than 30 mg/L and within the turbidity limit of 25 NTU (IMO Secretariat 2015).

3.4 Nitrogen

Nitrogen concentrations in the washwaters are elevated from natural seawater as the scrubbing process also results in the dissolution of nitric and nitrous oxides (NOx) produced during combustion. Some studies have measured this in the washwaters as total nitrogen, which includes both dissolved and particulate forms; or as nitrate-N or nitrite-N, soluble forms most available for primary producers. In studies conducted in the North Sea and Baltic Sea, the nitrate concentrations in the washwater from open-loop scrubber systems were at times slightly higher (e.g., 0-2 mg/L) than in the inlet waters (EGCSA and Euroshore 2018). In contrast, concentrations of 49-194 mg/L were measured in the washwaters from closed-loop scrubbers (EGCSA and Euroshore 2018, Magnusson et al. 2018). However, discharge rates from closed-loop scrubbers are much lower.

3.5 Metals

Vanadium and nickel are the metals at highest concentrations in the washwaters due to their presence in the heavy fuel oil. Copper, zinc and chromium are also found at elevated concentrations, though their presence is attributed to corrosion of the metal components (including brass components) within the treatment systems, due in part to low pH of the water. Rare earth elements such as lanthanum, scandium and cerium, may be present in the scrubber washwater as they are present in crude oils either naturally or as a result of the refining process (Yasnygina et al. 2006); however to date no studies have reported their presence (or absence) in the washwaters.

Concentrations of metals in washwaters from closed-loop and open-loop scrubbers are compared in Figure 3-2. In closed loop systems contaminants build up during recirculation and concentrations are therefore much higher than in open loop systems. However closed loop systems only discharge a bleed-off fraction to compensate for pollutant build-up, so the volume discharged is much lower than the open loop systems (see section 2.5).

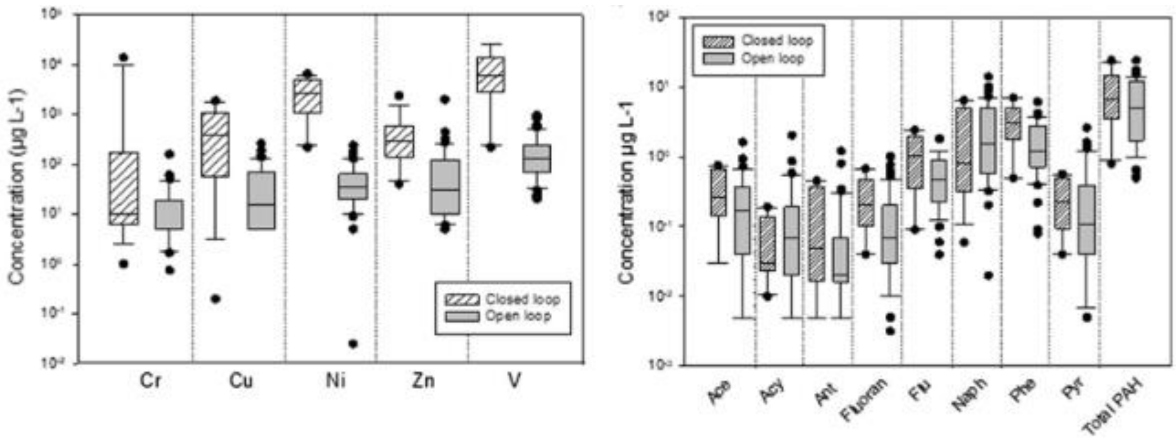


Figure 3-2: Comparison of metals (left) and selected PAHs (right) in discharges from closed-loop and open-loop scrubbers. From Teuchies et al. (2020). Box plots indicate median (line), 25th and 75th percentiles (box), 5th and 95th percentiles (whiskers) and outliers (dots). Note logarithmic y-axes.

The concentration of contaminants in the washwater is dependent upon the type of fuel oil being used (e.g. 0.1-4.5% S heavy fuel oils), with higher sulfur fuels generally generating washwaters with higher metal concentrations (presumably due to their being less refined). Samples collected under conditions of higher engine loading (e.g., 50% vs 80%) indicate that metal concentrations also increase as engine loading rates increase. Discharge rates also increase with higher engine load, thereby resulting in much higher contaminant loads discharged.

3.6 PAHs

PAHs are derived from the fuel oil and from incomplete combustion. Concentrations vary depending on both the particular compound and the study, though the light PAHs dominate of those PAHs typically measured (e.g., naphthalene (NAP) which are among the more toxic PAHs). As with metals, concentrations vary depending on scrubber type (higher in closed-loop scrubbers, see Figure 3-2), engine power and engine loading. Benzo[a]pyrene is the PAH of most carcinogenic concern and its concentrations range from <0.01 µg/L to 1.2 µg/L (median of 0.03 µg/L). Fluoranthene is the PAH of most concern relating to phototoxicity (Ahrens et al. 2002): its concentrations range from <0.01 to 1.0 µg/L, with a median of 0.08 µg/L.

Some studies have also measured alkylated PAHs and these have been shown to be present at similar or higher concentrations than the parent PAHs, and these compounds also have similar or higher levels of toxicity (or photoxicity) to parent PAHs. Any practical assessment of EGCS discharges should consider the possible effects of these compounds in addition to the 16 USEPA PAHs typically measured.

Some of the on-line techniques currently employed to monitor PAHs have been shown to be unreliable (USEPA 2011, Hufnagl 2005). On-line systems measure a proxy for total PAHs using fluorescence detectors which are prone to inaccuracies due to interferences from colour, air bubbles or turbidity. They define the concentrations as the fluorescence emitted by 1 µg/L of phenanthrene and is usually based upon normalized flow rate of 45 tons/MWh. Phenanthrene is a dominant compound observed in the 16 USEPA PAHs measured in EGCS discharges.

3.7 Hydrocarbons

Hydrocarbons, in terms of total petroleum hydrocarbons (TPHs) (aliphatic and aromatic hydrocarbons, usually C5-C40), have been measured in only two studies (Magnusson et al. 2018, Teuchies et al. 2020). Concentrations appear to be lower in open-loop scrubber washwaters (e.g., <0.1 mg/L – 2 mg/L) than in closed-loop systems where they may reach 30 mg/L in total.

TPHs are of potential concern for formation of thin surface films which may result in both aesthetic effects and ecological effects on intertidal organisms caused by coating during tidal cycles.

BTEX (benzene, toluene, ethylbenzene and xylene; simple aromatic hydrocarbons), have been detected in washwaters from both open and closed-loop systems with a maximum of 4.9 µg/L of benzene detected. There is insufficient data to demonstrate a clear difference between discharges from the open and closed-loop systems.

3.8 Additional contaminants

Two studies have investigated the presence of dioxins and furans (PCDDs / PCDFs[3]) in the washwaters (Magnusson et al. 2018) or in the sludge produced during washwater treatment (Kjølholt et al. 2012). No dioxins were found in the washwater from a closed-loop scrubber on the Stena Britannica (detection limits 0.9-3.6 pg/L; total < 4.6 pg/L TEQ). Dioxins were measurable in the sludges from the MV Ficaria Seaways Roropax vessel with the hybrid scrubber operating in closed-loop (freshwater) mode, at 16.2 and 26.3 ng/kg dry weight when operating with 2.2% S and 1.0% S HFO respectively.

[3] Polychlorinated dibenzodioxins and polychlorinated dibenzofurans

Polychlorinated biphenyls (PCBs) were investigated in washwater samples from a single vessel (Teuchies et al. 2020) and were not present (<0.02 µg/L for individual congeners) in the samples collected during either closed-loop or open-loop mode. There is no conceptual expectation that PCBs would be present in HFOs or as combustion products present within an EGC system.

3.9 Toxicity test results

Toxicity testing of discharges provides an integrated assessment of the toxicity of all components within the discharge, including those that are not easily measured by chemical methods. Several studies have investigated the toxicity of the discharge waters using a mixture of species from different taxonomic groups, including algae, crustacea, molluscs and fish (**Error! Reference source not found.**).

Most of the studies testing multiple dilutions of washwater reported that relatively high percentages of washwater (>10%) were required to elicit toxic effects (**Error! Reference source not found.**). Conversely, Magnusson et al. (2018) reported effects on juvenile copepod mortality and development at concentrations as low as 0.04% for closed-loop washwaters and 1% for open-loop washwaters. This may be due to the duration of these tests, at 7-14-days, being much longer than the <96-hours for most other tests. This longer duration testing would only be relevant for locations where there is little mixing of the scrubber discharges or a near-constant discharge from multiple vessels, such as in busy harbours and ports.

Table 3-2: List of studies that have assessed toxicity of scrubber washwaters.

Taxonomic group	Species	Test type and duration	Vessel	Scrubber type or operating mode	Findings	Reference
Microbes	*Vibrio fischeri*	Inhibition of luminescence (lumistox test)	Pride of Kent	Open-loop	<20% inhibition in samples of 100% scrubber washwater	Hufnagl et al. (2005)
Diatom	*Melosira* cf. *arctica*	Photosynthetic activity, primary productivity	Test scrubber	Open-loop	Increase in productivity at >5% scrubber washwater	Ytreberg et al. (2019)
Cyanobacteria	*Nodularia spumigena*	Photosynthetic activity, primary productivity	Test scrubber	Open-loop	Increase in productivity at ~15% scrubber washwater	Ytreberg et al. (2019)
Algae	*Rhodomonas* sp. (cryptophyte)	growth	Magnolia Seaways	Open-loop	Initial reduction in growth in 10% scrubber washwaters	Koski et al. (2017)
Algae	*Skeletonema costatum* (diatom)	72-hr growth rate	Test scrubber	Mixture of open-loop and closed-loop operation	Effects on growth at >32% scrubber washwaters	Koyama et al. (2018)
Crustacea	*Hyale barbicornis* (amphipod); juvenile	96-hr mortality	Test scrubber	Mixture of open-loop and closed-loop operation	Increased mortality at ≥25% scrubber washwater	Koyama et al. (2018)
Crustacea	*Acartia tonsa* (copepod), eggs and adults	Mortality	Magnolia Seaways	Open-loop	Increased mortality at >10% scrubber washwater	Koski et al. (2017)
Crustacea	*Calanus helgolandicus* (copepod, zooplankton); juvenile	Mortality, development, feeding rate and metabolic rate; 7-14 day test	Stena Britannica, Stena Transporter, Stena Forerunner	Closed loop, Closed loop, Open loop	Toxic effects at 0.04-1.0% scrubber washwater	Magnusson et al. (2018)
Crustacea	*Artemia salina* (brine shrimp); juvenile	24-hr mortality	Pride of Kent	Open-loop	No mortality in 100% scrubber washwater	Hufnagl et al. (2005)
Mollusca	*Mytilus edulis* (blue mussels; adults	Bysuss thread strength, hepatosomatic index and cell viability; 15-35 day test	Stena Transporter	Closed loop	Reduction in strength at 1.25% scrubber washwater	Magnusson et al. (2018)
Fish	*Oryzias javanicus* (Javanese ricefish); juvenile	96-hr mortality	Test scrubber	Mixture of open-loop and closed-loop operation	High mortality at ≥50% scrubber washwater	Koyama et al. (2018)

4 Hazard characterisation

The contaminants of concern can present a hazard for marine ecosystems through several pathways including changes to pH, contributing to eutrophication, and toxicity (Table 4-1). Water and sediment quality guidelines are available to assess the potential effects for some of these routes.

Table 4-1: Potential pathways for adverse effects from contaminants of concern.

Pathway	Contaminant of concern
Changes in pH	pH
Eutrophication	Nitrate
Toxicity through exposure in water	Metals, BTEX
Bioaccumulation and toxicity through dietary intake	Metals, PAHs
Toxicity through exposure in sediment	Metals, PAHs

4.1 Effects in water column

Changes in marine water pH may directly affect many marine organisms, particularly those that build skeletons and shells, but also changes the speciation of trace elements, thereby affecting their bioavailability and uptake (Lewis et al. 2016, Millero et al. 2009). To assess potential effects, a guideline of 0.2 unit pH change as recommended by US EPA and CCME (CCME 1999c, US EPA 1986) could be used as a guideline for the coastal environments. Estuaries typically have more variable pH and a greater change may be acceptable, however use of 0.2 units could be used as a conservative (screening level) guideline for this environment.

Possible eutrophication effects from increases in nitrate concentrations can be assessed from guidance in the NZ Estuary Trophic Index (ETI) tool (Zeldis et al. 2017). This provides values for potential total nitrogen concentrations that correspond to macroalgal growth response. Minimal macroalgal growth (minimal eutrophication) is expected where TN is below 0.08 mg/L. This guideline is suitable for assessing effects in ports, but not for open coastal areas like shipping lanes. A value of 0.17 mg/L TN was calculated by (Dudley et al. 2019) as a threshold for controlling planktonic chlorophyll-*a* growth and may be suitable for this assessment. However, for assessing the potential effects from nitrogen on marine ecosystems, the total *loads* discharged are the most important aspect for consideration, rather than the *concentrations* in the discharge or the receiving environment after mixing.

The toxic effects of contaminants from exposure through water can be assessed using water quality guidelines (Table 4-2) which are available for New Zealand for most metals of interest and some PAHs; or could be adopted from other jurisdictions. An alternative approach is to determine thresholds for specific species of interest, or life stages (for example larval stages of shellfish) such as might be present in aquaculture facilities. Such information may already be available for some metals, though not necessarily for New Zealand species. This approach has been used for a risk assessment for chemical contaminant exposure for aquaculture species resident at NIWA’s Bream Bay facility (Clearwater 2009).

Table 4-2: Water quality guidelines for potential use in assessing adverse effects related to toxicity.

Contaminant / stressor	Guideline type	Guideline value	Source / Reference[3]
Metals and metalloids			
As	USEPA chronic criteria (CCC)[1]	36 µg/L	US EPA (1996)
Cd	Toxicity, protect 99% of species, default that accounts for bioaccumulation	0.7 µg/L	ANZG (2018)
Cr (III)	Toxicity, protect 99% of species	7.7 µg/L	ANZG (2018)
Cr (VI) [2]	Toxicity, protect 99% of species	4.4 µg/L	ANZG (2018)
Cu	Toxicity, protect 99% of species	0.3 µg/L	ANZG (2018)
Hg	Toxicity, protect 99% of species	0.1 µg/L	ANZG (2018)
Pb	Toxicity, protect 99% of species	2.2 µg/L	ANZG (2018)
Ni	Toxicity, protect 99% of species	7 µg/L	ANZG (2018)
Se	Low reliability guideline British Columbia	3 µg/L 2 µg/L	(ANZECC 2000); (Beatty & Russo 2014)
V	Toxicity, protect 99% of species	50 µg/L	ANZG (2018)
Zn	Toxicity, protect 99% of species; Draft guideline toxicity, protect 99% of species	7 µg/L 1.8 µg/L	ANZG (2018); ANZG (2020)
PAHs			
Naphthalene	Toxicity, protect 99% of species	50 µg/L	ANZG (2018)
Fluoranthene	Toxicity, protect 99% of species	1 µg/L	ANZG (2018)
Phenanthrene	Toxicity, protect 99% of species	0.6 µg/L	ANZG (2018)
Anthracene	Toxicity, protect 99% of species	0.01 µg/L	ANZG (2018)
Benzo[a]pyrene	Toxicity, protect 99% of species	0.1 µg/L	ANZG (2018)

Note:1 CCC: Criterion Continuous Concentration; n estimate of the highest concentration of a material in the water column to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect. 2 Form most likely to be present in marine waters; 3 ANZG 99% species protection values.

An initial screening of the discharge quality against these water quality guidelines (Table 4-3) indicates that most of the contaminants in the washwaters prior to any dilution in marine receiving waters are present at concentrations that exceed guideline values. In particular, the 95th percentile concentrations calculated here are several orders of magnitude higher than the guideline values, with highest exceedances for chromium, nickel, vanadium and zinc. This assessment indicates that the contaminants of concern in relation to aquatic toxicity are chromium, copper, lead, nickel, zinc and anthracene.

Table 4-3: Comparison of contaminants in scrubbers discharges with water quality guidelines. All data in µg/L. Yellow shaded cells represent concentrations less than an order of magnitude above the guideline value, orange shaded cells represent concentrations more than an order of magnitude above the guideline value.

Contaminant / stressor	Guideline value [1]	Discharge concentrations [2]		Comment
		Median	95th percentile	
As	36	8.75	24	
Cd	0.7	0.065	0.66	
Cr (III) [2]	7.7	22	2034	Chromium species not measured separately in these studies
Cr (VI) [2]	4.4	22	2034	
Cu	0.3	43	233	Copper derived from metal fittings on vessels
Hg	0.1	0.064	0.097	Mercury likely to be represent a greater risk through food-chain bioaccumulation, see section 4.3
Pb	2.2	3.8	77	
Ni	7	44	4385	
Se	2-3	94	94	Only measured in one study
V	50	159	14000	
Zn	1.8-7	100	841	
Naphthalene	50	1.2	7.5	
Fluoranthene	1	0.12	0.60	
Phenanthrene	0.6	1.4	4.4	
Anthracene	0.01	0.036	0.46	
Benzo[a]pyrene	0.1	0.034	0.30	

Note: 1 These values are from Table 4-2 for high levels of species protection as appropriate for pristine waters. Lower levels of protection may be more appropriate for ports and harbours. 2 For this initial assessment these values have been calculated from all available data, regardless of scrubber type, engine power or loading. Data below detection limit not included in calculations.

4.2 Sediment quality

The effects of contaminants accumulating in sediment can be assessed using sediment quality guidelines (Table 4-4). These are available for most metals and for total PAHs and TPH (total petroleum hydrocarbons). The guidelines are derived from distributions of concentrations in sediment that are associated with adverse biological effects (CCME 1999a).

The effects of the washwaters on sediment quality cannot be assessed through a simple comparison of the discharge to sediment quality guidelines (as conducted above for water quality guidelines), and some modelling (e.g., of the partitioning to sediments) is needed to make this assessment.

Table 4-4: Sediment quality guidelines for potential use in assessing adverse effects.

Contaminant / stressor	Sediment quality guideline value	Source / Reference
As	7.2 mg/kg	(CCME 1999a)
Cd	1.5 mg/kg	ANZG (2018)
Cr	80 mg/kg	ANZG (2018)
Cu	65 mg/kg	ANZG (2018)
Hg	0.15 mg/kg	ANZG (2018)
La	39 mg/kg	Freshwater sediment, Herrmann et al. (2016)
Pb	50 mg/kg	ANZG (2018)
Ni	21 mg/kg	ANZG (2018)
Se	2 mg/kg	(Beatty & Russo 2014)
V	130 mg/kg	No sediment guideline from ANZG or CCME Soil guideline from (CCME 1999b)
Zn	200 mg/kg	ANZG (2018)
Total PAHs	10 mg/kg [1]	ANZG (2018)
TPH	280 mg/kg	ANZG (2018)

Note: [1] Normalised to 1% organic carbon.

4.3 Bioaccumulation and human health effects

Several of the metals (including mercury, cadmium and lead), the rare earth elements and PAHs can bioaccumulate and therefore represent a hazard to both the aquatic organisms, and to those consuming them, including humans. Mercury has been detected at ng/L concentrations in the scrubber washwater discharges, and has potential to accumulate in biota and biomagnify to higher concentrations at higher trophic levels. Mercury is of particular concern for human health from consumption of shellfish and fish with elevated methylmercury. Lead is also bioaccumulative and leads to adverse effects on fish, and is harmful for human health, particularly for young children who are at risk of development and neurological effects (US EPA 2019b). Lead has been measured in the discharges and varies by 3 orders of magnitude from 0.1 to 120 µg/L (see Appendix A). Studies show that many rare earth elements also bioaccumulate, though at present there is insufficient information to assess the potential effects from this hazard (MacMillan et al. 2017).

Benzo[a]pyrene is classified by the International Agency for Research on Cancer as a known carcinogen; and other PAHs are classed as possible carcinogens (IARC 2019). Benzo[a]pyrene also has the higher potential to bioaccumulate than the lower molecular weight PAHs (e.g., naphthalene, phenanthrene and fluoranthene) that are present at higher concentrations in the discharges.

Bioaccumulation is potentially a very important component for effects on higher trophic level organisms including whales; and for food-chain accumulation including in shellfish beds and aquaculture facilities, and potential consumption by people. As with sediment, it is not possible to undertake an initial screening of the discharge data against guidelines based on fish or shellfish consumption.

5 Exposure assessment

5.1 Introduction

Exposure assessment is the step of the risk assessment where the concentrations of contaminants that organisms are exposed to are described. The exposure rates can be expected to depend on:

- The number of vessels with scrubbers operating in any given location, which also depends on the engine the scrubbers are connected to (main or auxiliary),
- The type of scrubber (open-loop or closed-loop),
- Discharge rates, which depend on the type of scrubber, vessel type, engine power / size and its operating power output at the time of discharge,
- Dilution and dispersion of the discharged washwater – which will differ for different vessels and environments.

One way of assessing exposure for a risk assessment would be to measure the concentrations of contaminants within the receiving environment around vessel discharges. Hufnagl et al. (2005) used this approach in their assessment of effects of sea water scrubbers, collecting water samples in Dover, Calais and the channel during the passage of the Pride of Kent, discharging from an open-loop scrubber. This assessment did not identify clear effects from the scrubber discharge except for a change in pH.

However, collecting samples in receiving waters is very difficult for the contaminants at trace concentrations and is not suitable for assessing future uptake of scrubbers. This method is not recommended for assessing risks in New Zealand waters. The alternative approach of predicting the concentrations using some form of model is recommended, based on the loading of contaminants discharged from scrubbers and dilution in the environment.

5.2 Number of ships in NZ waters using scrubbers

Under MARPOL Annex VI, vessels are expected to contact New Zealand maritime authorities before entering New Zealand waters to notify compliance with the regulations, including providing information on scrubber type. However, this reporting is not mandatory and is not expected to be a suitable source of information on the total number of vessels using scrubbers. The signatory nations to the MARPOL Annex VI should hold information on whether vessels registered to them have scrubbers installed and have information about those scrubbers. MfE and Maritime New Zealand are requesting this information from the 10 nations that have most vessels visiting New Zealand. However, this information may not be forthcoming.

The IMO registration numbers of vessels entering New Zealand can be obtained from data from the New Zealand Customs Service. Information on ships with scrubbers is available from IMO's Global Integrated Shipping Information System (GISIS) website. There are currently close to 2500 ships listed there as having exhaust gas cleaning systems (Table 5-1). However, this database does not provide a complete record of all ships that have scrubbers fitted, as industry sources indicate that about 4000 ships now have scrubbers fitted[4]. Furthermore, in the IMO GISIS database, data on the type of vessel or the type of scrubber are not easily available for compilation, though it is searchable by vessel

[4] https://shipandbunker.com/news/world/814936-number-of-ships-to-be-equipped-with-scrubbers-hits-4000-dnv-gl

number (Figure 5-1). The information available generally shows what type of scrubber (open-loop, closed-loop or hybrid) and which engines the scrubbers operate on (Figure 5-2, also an example of the additional information provided by some states is in Appendix B).

Based on some preliminary checks of the IMO GISIS for the top 45 vessels that visited New Zealand in 2019, there were only 6 vessels that had reported their use of scrubbers to the IMO. All of these were cruise ships and 3 out of 6 had open-loop systems installed. Cruise ships visiting New Zealand visit parts of New Zealand that other ships do not (e.g., Akaroa Harbour, Milford Sound) and therefore represent a potential risk to these marine environments, that are less affected by other vessels.

To estimate the number of vessels in New Zealand using scrubbers, information will need to be compiled from existing data sources providing data on the vessels entering New Zealand (see Table 5-2), the characteristics of those vessels and international data on scrubber use, for example the proportion of the global fleet that have scrubbers installed, by vessel type, as published in 2020 (Table 5-3). This assumes that the proportions in vessels visiting New Zealand is the same as the global proportions, which may be an over- or under-estimate. As this would not account for future installations of scrubbers, some predictions of future uptake needed to be incorporated.

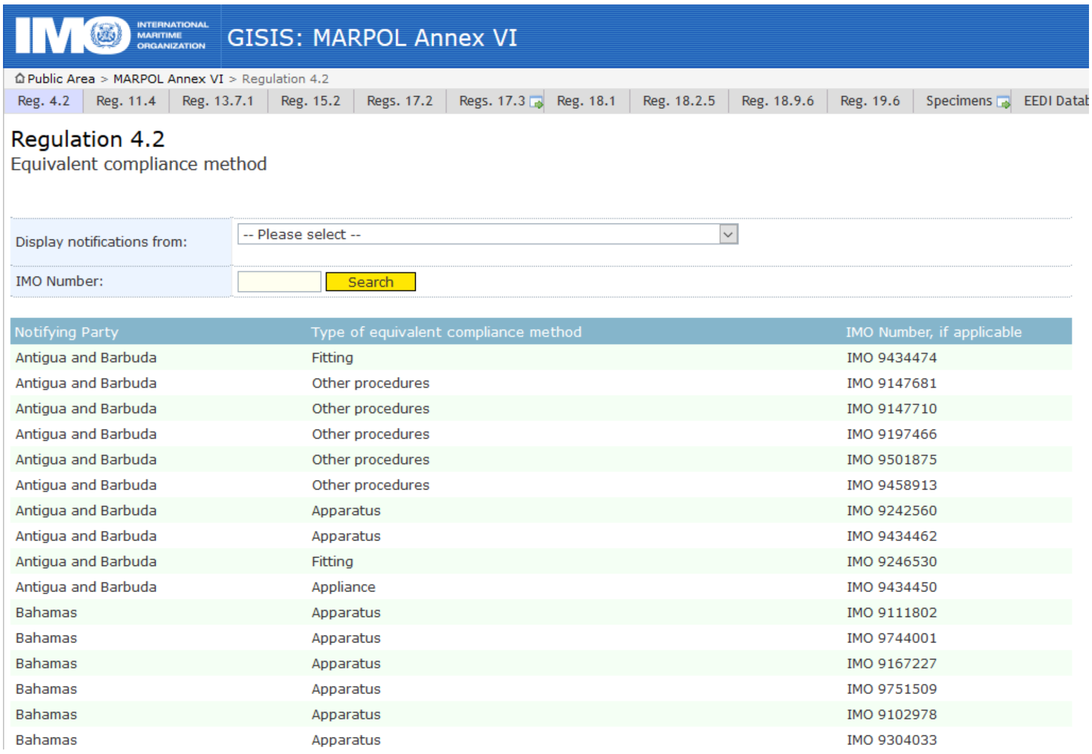
Predictions of future uptake of scrubbers are variable as this depends on the price difference between compliant low sulfur fuel oil (LSFO) and non-compliant high sulfur fuel oil (HSFO). It was reported in 2018 that there were 60,000-90,000 ships that were potential candidates for scrubbers.[5] With estimates of 4,000 ships using scrubbers by 2020, this equates to 4-6% of the global fleet. Some estimates project 7,000-10,000 installations by 2025 – totalling up to 16% of the global fleet.[5] A most probable scenario posited that around 10% of the fleet would have scrubbers by the end of 2030[5], approximately double that of the number in 2020. Others have predicted up to 30% of shipping owners will install scrubbers[6], though it is not clear whether this would equate to 30% of vessels. These predictions could be used to estimate the number vessels in New Zealand waters using scrubbers currently and in the future, based on an increase of 2-3 times the current numbers.

The number of vessels in each location of interest (for example, in a shipping lane or harbour) is not available from the customs database as this only registers the vessel if it was the first port of arrival to New Zealand. This information could be obtained from the outputs from the Lloyds database that New Zealand currently has access to, which are from 2000-2005 and for 2016 only. Alternatively Maritime NZ or the port authorities may be able to provide this information.

[5] https://safety4sea.com/cm-scrubbers-risk-and-opportunities/
[6] https://www.seatrade-maritime.com/asia/foreship-predicts-30-ships-will-use-scrubbers-2030

Table 5-1: Summary of alternative compliance methods reported to IMO GISIS under regulation 4.2 of MARPOL Annex VI as at July 2020. Summary from (IMO Secretariat 2020).

Notifications received from	EGCS	LNG and fuel oil mixture	Sulphur emissions averaging scheme	Fuel blending	Biofuel
Antigua and Barbuda	3			5	
Bahamas	73	14	4		
Belgium	4				
Canada	7				
Cayman Islands (United Kingdom)	18				
Cyprus	52	2			
Denmark	69				1
Faroes, Denmark	5				
Finland	26				
France	5				
Germany	13			2	
Gibraltar (United Kingdom)	1				
Greece	95				
Hong Kong, China	168				
India	3				
Isle of Man (United Kingdom)	39				
Italy	34				
Japan	40				
Liberia	335				
Lithuania	5				
Malaysia	2				
Malta	164	2	5		
Marshall Islands	480				
Netherlands	53				
Norway	37				
Panama	323	2			
Portugal	35				
Republic of Korea	15				
Saudi Arabia	1				
Singapore	140				
Spain		1			
Sweden	5				
Turkey	13				
United Kingdom	91				
United States	5				
Total	**2,359**	**21**	**9**	**7**	**1**



GISIS: MARPOL Annex VI

Public Area > MARPOL Annex VI > Regulation 4.2

Reg. 4.2 | Reg. 11.4 | Reg. 13.7.1 | Reg. 15.2 | Regs. 17.2 | Regs. 17.3 | Reg. 18.1 | Reg. 18.2.5 | Reg. 18.9.6 | Reg. 19.6 | Specimens | EEDI Datal

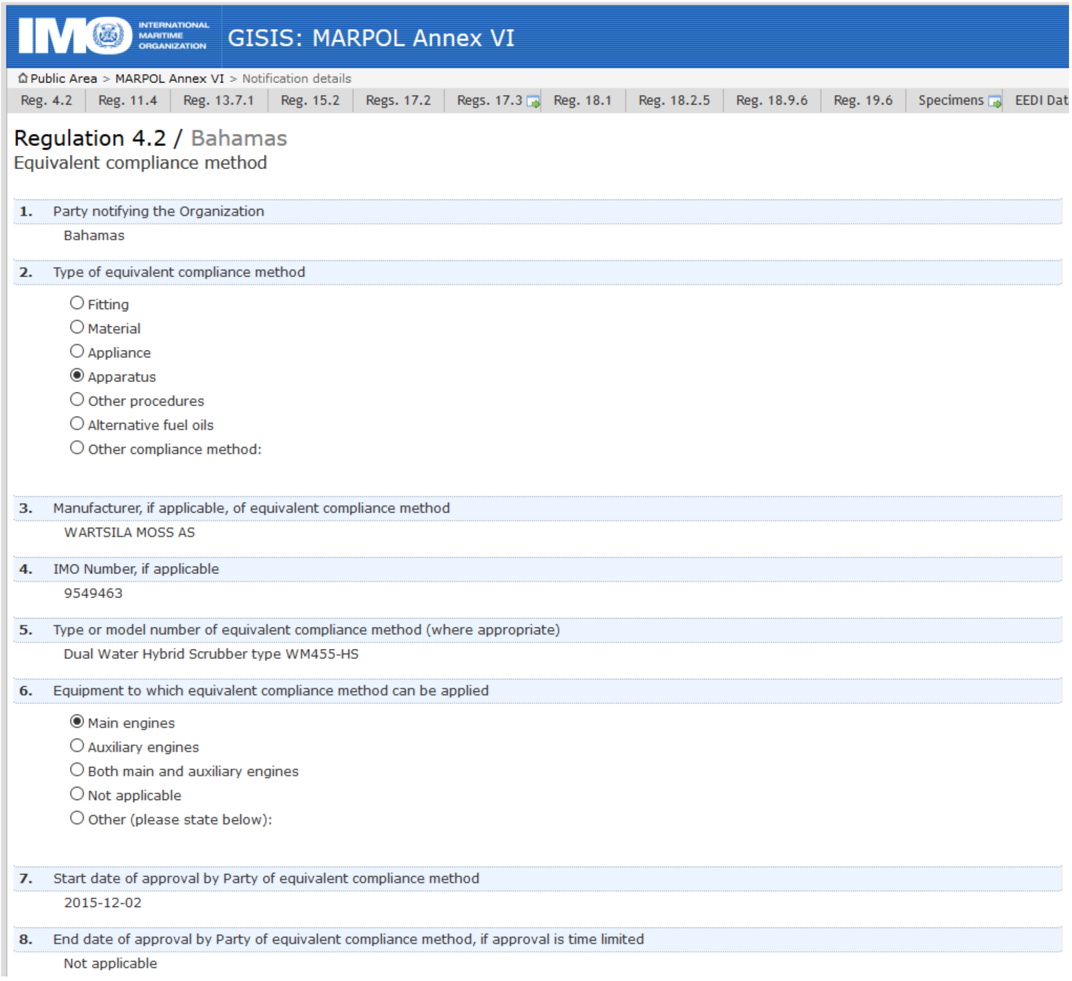
Regulation 4.2
Equivalent compliance method

Display notifications from: -- Please select --

IMO Number: Search

Notifying Party	Type of equivalent compliance method	IMO Number, if applicable
Antigua and Barbuda	Fitting	IMO 9434474
Antigua and Barbuda	Other procedures	IMO 9147681
Antigua and Barbuda	Other procedures	IMO 9147710
Antigua and Barbuda	Other procedures	IMO 9197466
Antigua and Barbuda	Other procedures	IMO 9501875
Antigua and Barbuda	Other procedures	IMO 9458913
Antigua and Barbuda	Apparatus	IMO 9242560
Antigua and Barbuda	Apparatus	IMO 9434462
Antigua and Barbuda	Fitting	IMO 9246530
Antigua and Barbuda	Appliance	IMO 9434450
Bahamas	Apparatus	IMO 9111802
Bahamas	Apparatus	IMO 9744001
Bahamas	Apparatus	IMO 9167227
Bahamas	Apparatus	IMO 9751509
Bahamas	Apparatus	IMO 9102978
Bahamas	Apparatus	IMO 9304033

Figure 5-1: Snapshot of list of vessels on IMO GISIS website with a MARPOL Annex VI compliance method.



GISIS: MARPOL Annex VI

Public Area > MARPOL Annex VI > Notification details

Reg. 4.2 | Reg. 11.4 | Reg. 13.7.1 | Reg. 15.2 | Regs. 17.2 | Regs. 17.3 | Reg. 18.1 | Reg. 18.2.5 | Reg. 18.9.6 | Reg. 19.6 | Specimens | EEDI Dat

Regulation 4.2 / Bahamas
Equivalent compliance method

1. Party notifying the Organization
   Bahamas

2. Type of equivalent compliance method
   - ○ Fitting
   - ○ Material
   - ○ Appliance
   - ◉ Apparatus
   - ○ Other procedures
   - ○ Alternative fuel oils
   - ○ Other compliance method:

3. Manufacturer, if applicable, of equivalent compliance method
   WARTSILA MOSS AS

4. IMO Number, if applicable
   9549463

5. Type or model number of equivalent compliance method (where appropriate)
   Dual Water Hybrid Scrubber type WM455-HS

6. Equipment to which equivalent compliance method can be applied
   - ◉ Main engines
   - ○ Auxiliary engines
   - ○ Both main and auxiliary engines
   - ○ Not applicable
   - ○ Other (please state below):

7. Start date of approval by Party of equivalent compliance method
   2015-12-02

8. End date of approval by Party of equivalent compliance method, if approval is time limited
   Not applicable

Figure 5-2: Snapshot of example of information on scrubbers available for vessels on IMO GISIS website.

Table 5-2: Data sources for vessel numbers and movements around New Zealand.

Description	Time period covered	Source	Content	Issues
Domestic Vessel Movements Study	2000-2005	Lloyds List Intelligence / NIWA	Older dataset of ship movement data, includes all vessels in NZ waters, with port to port movement data.	
New Zealand (NZ) Ballast water declarations	Jan 1998 - Feb 2008	MPI Intelligence & Targeting team	Ballast water releases / Biofouling risk. Includes similar information to that found in the MPI Intelligence vessel arrival excel spreadsheets, but is older.	
Vessel Movements	2016	Lloyds List Intelligence	Ship movement data, includes all vessels in NZ waters, with port to port movement data.	
Vessel arrivals by arrival port	May 2015-Apr 2017	MPI Intelligence & Targeting team	Arrival information and ballast water declarations of all overseas vessel arrivals into NZ. Last overseas port and next overseas port are recorded. Does include some NZ domestic movement information but it is not clear where vessels have arrived from and where they are going.	Issues teasing out the correct information as MPI do not store vessel arrival information linked with the ballast water and biofouling questions. There are differences in questions between years so the data has not been combined. Separate tabs are available for each year.
New Zealand (NZ) Biofouling and Ballast Water Declarations	Mar 2016 - Dec 2016	MPI Intelligence & Targeting team	Ballast water releases / Biofouling risk. Includes similar information to that found in the MPI Intelligence vessel arrival excel spreadsheets, but this is newer data that has not all been entered.	Only 473 entered, but there are 6147 records of ballast uptake or exchange.
MoT annual vessel visits by port	2013-2018	Ministry of Transport	Individual vessel arrivals into NZ ports by date, vessel type and tonnage (no individual vessel identification numbers, i.e. no IMO numbers).	Shows changes in vessel arrivals through time at NZ ports.
Vessel arrivals to initial port	Jan 2017 - Dec 2019	NZ Customs Service database	Includes the vessel category, IMO number, gross tonnage.	Only shows the initial port of arrival, does not include movements around NZ.

Table 5-3: Proportion of global fleet with open-loop or hybrid scrubbers by ship type in 2020. Summary from DNV-GL (2018) and HIS (2018) as cited in IMO Secretariat (2020).

Ship type	Proportion of ships
Bulk carrier	11%
Chemical tanker	5%
Container	15%
Cruise	69%
General cargo	1%
Oil tanker	7%
Roll-on/roll-off	26%
Vehicle carrier	4%

Source: DNV-GL (2019) and IHS (2018)

5.3 Total discharge rates and volumes

As described in Section 2.5, the rate of scrubber washwater discharged from a single vessel depends on the type of scrubber and its operating mode (open-loop vs closed loop), the engine size (power) and engine loading. For vessels identified from IMO GISIS database as using scrubbers, the type of scrubber can also be identified and for most vessels the information also specifies whether the scrubbers are connected to the main or auxiliary engine or both. In some cases, additional information is supplied that includes the engine size. Other sources of information on scrubber usage are unlikely to provide such details.

None of the shipping database information that we currently have access to provides data on the engine of size of individual vessels. This information would be available for purchase from Lloyds and may be provided through the request to the flag nations. In some cases, information on engine size is available through websites with shipping or maritime information (e.g., https://www.balticshipping.com/vessel/imo/9270907) however these would need to be searched manually for each vessel and may or may not have the required information.

Alternatively, estimates of engine size for different vessel types by gross tonnage could be used. Such estimates were used in a model of shipping emissions to air (Aulinger et al. 2016) and are provided for seven vessel types and nine classes of gross tonnage (see example in Table 5-4).

Higher engine loads are expected when vessels are at sea and lower rates are expected when vessels are travelling at lower speeds within harbours. When at port, although stationary, most vessels still have engines running (primarily auxiliary engines) and are therefore still emitting exhaust gases and may still be using scrubbers if the scrubbers are attached to both main and auxiliary engines. Studies of shipping emissions to air (e.g., Aulinger et al. 2016, De Meyer et al. 2008, Tzannatos 2010) are also a source of information on shipping engine loading rates, either for at port or en route. Most of these incorporated surveys of ship operators to obtain information on engine loading rates and have reported these load factors for different vessel types while at sea, at anchor, manoeuvring or at berth (hotel mode) (De Meyer et al. 2008, US EPA 2011, Whall et al. 2002). For example, to estimate emissions in the Greek port of Piraeus, Tzannatos (2010) acquired actual information on engine size for each vessel from Lloyds and obtained engine loading factors from ship operators. Aulinger et al. (2016) took a different approach and calculated engine loading from the vessel speed (obtainable from AIS data) and its maximum design speed, based on typical values for vessels of that type and size. Estimates for use in emission inventories are supplied in Browning (2009) and are an example of the information that could be used in this risk assessment.

Table 5-4: Estimates of engine sizes for cargo ships of varying sizes. Source: Aulinger et al. (2016).

Gross tonnage	Main engine size (kW) [1]	Auxiliary engine size (kW)
< 100	-	-
< 1600	-	-
< 3000	749	328
< 5000	2400	550
< 10 000	4690	1213
< 30 000	10 400	2284
< 60 000	21 068	7400
< 100 000	57 100	9416
≥ 100 000	68 640	13 188

Note: [1] Maximum continuous rating (rated power output).

5.4 Dilution and dispersion models

Dispersion of scrubber washwater discharges is highly dependent on whether the vessel is moving or at berth. As the washwaters are discharged through the ship's hull, below the waterline and a few meters from the propeller, there is considerable dispersion when in transit. When stationary (at port) there will be much less dispersion and therefore potential for contaminants to be at higher concentrations. On the other hand not all vessels would discharge scrubber washwaters when at port. This depends firstly, on whether the scrubbers are attached to the main or auxiliary engines (or both) and which engines are in use at port; and secondly, whether the scrubber is operating in closed loop mode, in which case there is capability to store the washwater and only discharge when at sea.

Dispersion of washwater discharges from vessels has been modelled with numerical models including computational fluid dynamics modelling for vessels both in transit and within port. When in transit, the propeller and wake of the ship create considerable turbulence, and this is the dominant dilution process (US EPA 2011). Initial mixing is dependent on the ship's length and velocity (Koyama et al. 2018). Over 1000-fold dilution was calculated after 10 seconds for a 222 m ship travelling at 12 knots (Koyama et al. 2018). This level of dilution was calculated within 50 m of the ship for a 230 m ship travelling at 24 knots using a different model (Buhaug et al. 2006).

The Swedish Environmental Research Institute Ltd, IVL (Magnusson et al. 2018), estimated dilution rates in the mixing zone, immediately behind vessels, from an equation based on ship size and speed (Equation 5-1). Dilution factors were estimated at 16,000 to 670,000 for three vessels each of 27 to 32 m in width, draft 6.3 to 6.7 m and travelling at 8.7 m/s.

$$Dilution\ factor = \frac{ship\ width \times ship\ draught \times ship\ speed}{discharge\ rate}$$ **Equation 5-1**

For a ship manoeuvring at port, with a speed of 4 knots, the dilution at 50 m behind the vessel was again >1000-fold. For a moored vessel, the dispersion of discharges will be strongly influenced by local conditions, including water depth, flow and sea temperature. One scenario, based on velocity of 0 knots, and an ambient current speed of 5 cm/s, calculated dilution of 1:100 in the centre of the plume within 20 m of the vessel. However, dilution can be expected to be lower than that in many situations as that scenario modelled the discharge with a temperature of 7.5°C, and a warm washwater discharge would be expected to form a buoyant plume near the water surface rather than mix vertically.

For modelling dilution and contaminant concentrations in ports and harbours, the MAMPEC model (Marine Antifouling Model for Predicting Environmental Concentrations) was one of three models suggested for further investigation as to its suitability (Linders et al. 2019). It has already been used to model changes in pH, nutrients and COD from scrubber discharges for three areas in Japanese coastal waters (Koyama et al. 2018). MAMPEC is a steady-state integrated hydrodynamic and chemical fate model that was developed for predicting the concentrations of antifouling substances. Although it requires only limited input data and is simple to set up, it is based on physical process-based models of dispersion, contaminant partitioning and degradation, and sedimentation. MAMPEC has been previously used in New Zealand for assessing antifouling risks and model input data are available for 11 ports and 13 marinas (Gadd et al. 2011) and would be suitable for use in risk assessments of scrubber discharges.

Two other models were suggested as being potentially suitable for assessing risk, including STEAM3 (Ship Traffic Emission Assessment Model) which uses AIS data to estimate air emissions (Jalkanen et al. 2009) and could potentially be amended for water emissions (Linders et al. 2019). However the STEAM3 model currently has no capability for modelling water discharge dispersion and dilution. The DREAM model (Dose-related risk and effects assessment model), developed to model drilling discharges in the ocean and including assessments of fate deposition and mixing) was also evaluated by Linders et al. (2019). While this could be applied to shipping washwater discharges, it would require substantial effort.

5.5 New Zealand coastal hydrodynamic models

There are a large number of locations around New Zealand where hydrodynamic models have been set-up and calibrated, including the major ports (Table 5-5). These models could be used to predict the environmental concentrations of contaminants from the washwater discharges based on the dilution and dispersion characteristics of each location. In most cases the models extend out of the port and harbour entrance into the coastal area and there may therefore be potential to use these models for predicting concentrations in coastal shipping lanes as well as in ports and harbours. These models are only likely to be suitable for a high tier risk assessment as they require specialist expertise to set-up and run each model.

Maps and models of tidal currents around New Zealand (e.g., Figure 5-3) may also be useful in identifying the likely transport and distribution pathways for discharges from vessels, when visualised alongside shipping lane densities. This would provide a qualitative assessment of the likely pathways.

Table 5-5: Ports and areas of New Zealand where hydrodynamic models have been developed.

Port / Location	Model types and developers
Bay of Islands	SELFE model, MetOcean
Whangarei Harbour	NIWA; MetOcean
Hauraki Gulf including Rangitoto Channel	NIWA
Waitemata Harbour	Delft 3D, NIWA; SELFE model, MetOcean
Manukau Harbour	Delft 3D, NIWA
Tauranga Harbour	Delft 3D, NIWA; SELFE model, MetOcean
New Plymouth	SELFE model, MetOcean
Wellington Harbour	NIWA
Queen Charlotte Sound and Tory Channel	ROMS, NIWA
Tasman Bay & Golden Bay	ROMS, NIWA
Lyttelton Harbour	SELFE model, MetOcean
Akaroa Harbour	Delft 3D, NIWA
Otago Harbour	SELFE model, MetOcean
Bluff Harbour	SELFE model, MetOcean

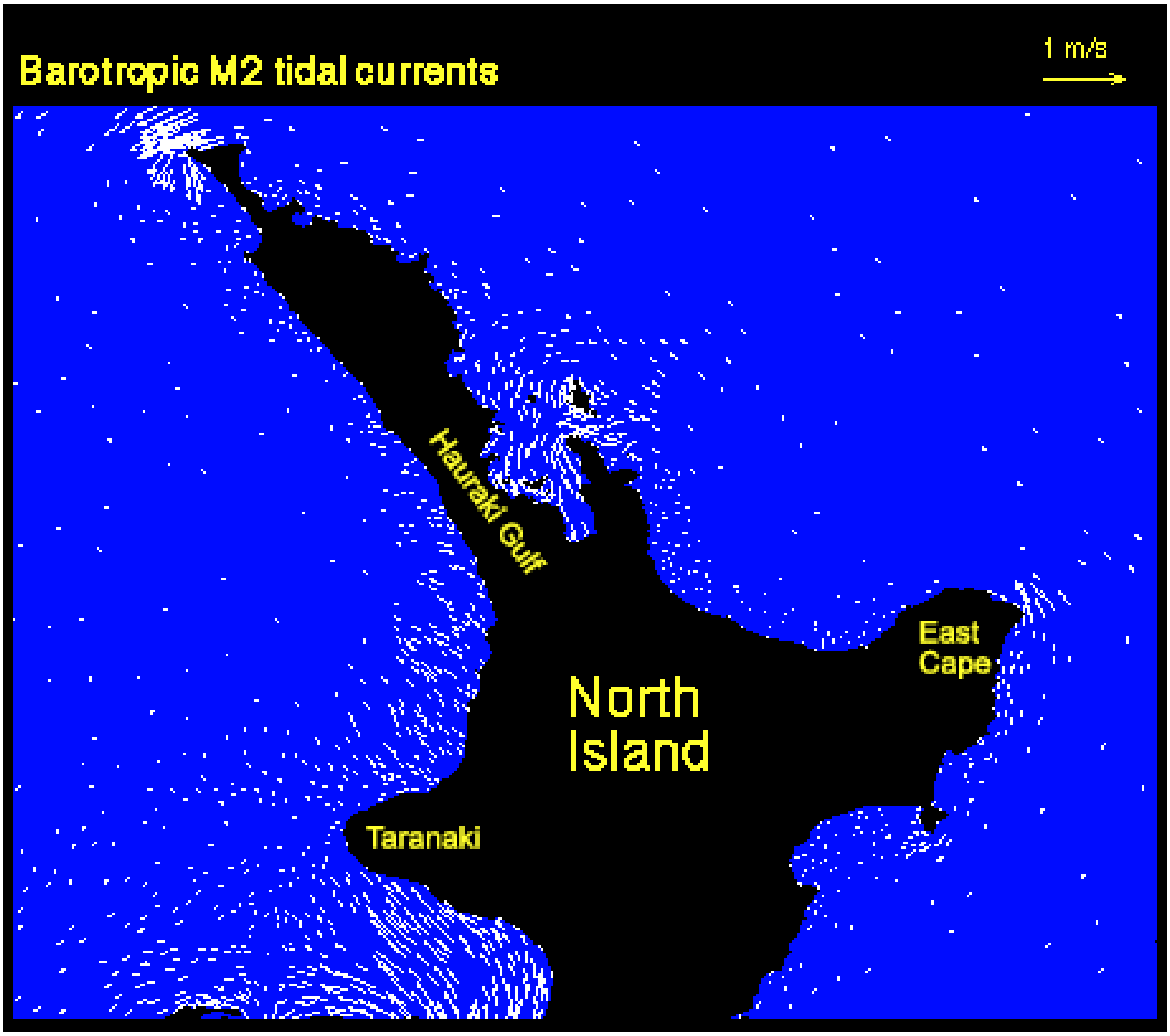


Figure 5-3: Snapshot of twice-daily M2 tidal currents animation around the North Island of New Zealand based on a TIDE2D model. Figure from NIWA (undated).

6 Locations with high potential risk

There are locations where the risk to marine ecosystems may be higher than on average, for example where vessel numbers are high and within areas of high ecological significance. Such locations may present specific case studies for the future risk assessment.

The routes of ships travelling around New Zealand are shown in Figure 6-1, overlaid with key aquaculture locations and various marine protected areas. These include marine reserves, benthic protection areas, marine mammal sanctuaries and marine protected areas. There are several locations where the shipping routes go through marine mammal sanctuaries including near Cook Strait, north of Banks Peninsula and near Taranaki. Shipping also passes through the Hikurangi marine reserve near Kaikoura [7]. These areas are of potential concern and could be included as specific locations for the risk assessment.

There is other information that should be added to this assessment to identify locations of high risk in relation to vessel discharges. This includes the locations of:

- Interest and concern to local iwi, including rohe moana (customary fishing) areas, as determined through the scoping undertaken for this project concurrent with this report.
- Significant Ecological Areas (SEAs) as defined by regional councils[8]. For example, Northland Regional Council's maps of SEAs includes areas around North Cape and Whangarei Harbour that may overlap with shipping lanes.
- Important bivalve shellfish bed areas (e.g. commercial, recreational and customary fishery areas) including for example scallops (*Pecten novaezelandiae*), mainly around Northland, Coromandel, Golden Bay, Tasman Bay and Marlborough Sounds (see Figure 6-2 for areas around Coromandel); oysters (*Ostrea chilensis*) in Foveaux Strait; cockles (*Austrovenus stutchburyi*) within Otago Harbour and other nearby inlets; Snake Bank, Whangarei Harbour; Tasman and Golden Bays; and clams of multiple species and areas, in particular pipi (*Paphies australis*) at Mair Bank in Whangarei Harbour.
- Other areas of importance for fisheries management, such as shellfish or finfish spawning grounds, fish nurseries and fish migration routes.
- Areas with high densities of marine mammals, for example as mapped in Figure 6-3.
- Major sea bird colonies including gannet colonies and albatross colonies (for example around Otago Harbour).
- Marine spatial planning exercises, such as the Hauraki Gulf Marine Spatial Plan (Sea Change – Tai Timu Tai Pari) which consider cultural, social and environmental aspects.

This work should be undertaken as the first task in Phase 2 and the information gathered from the cultural scoping should also be considered in that task for determining key locations of interest.

[7] Shipping routes also pass through the marine protected areas in Cook Strait and Hauraki Gulf, however these exist largely to protect the submarine cables present there rather than marine biodiversity.

[8] See https://nrcgis.maps.arcgis.com/apps/webappviewer/index.html?id=a8e411843cc749d3af8eab5a7b26f196

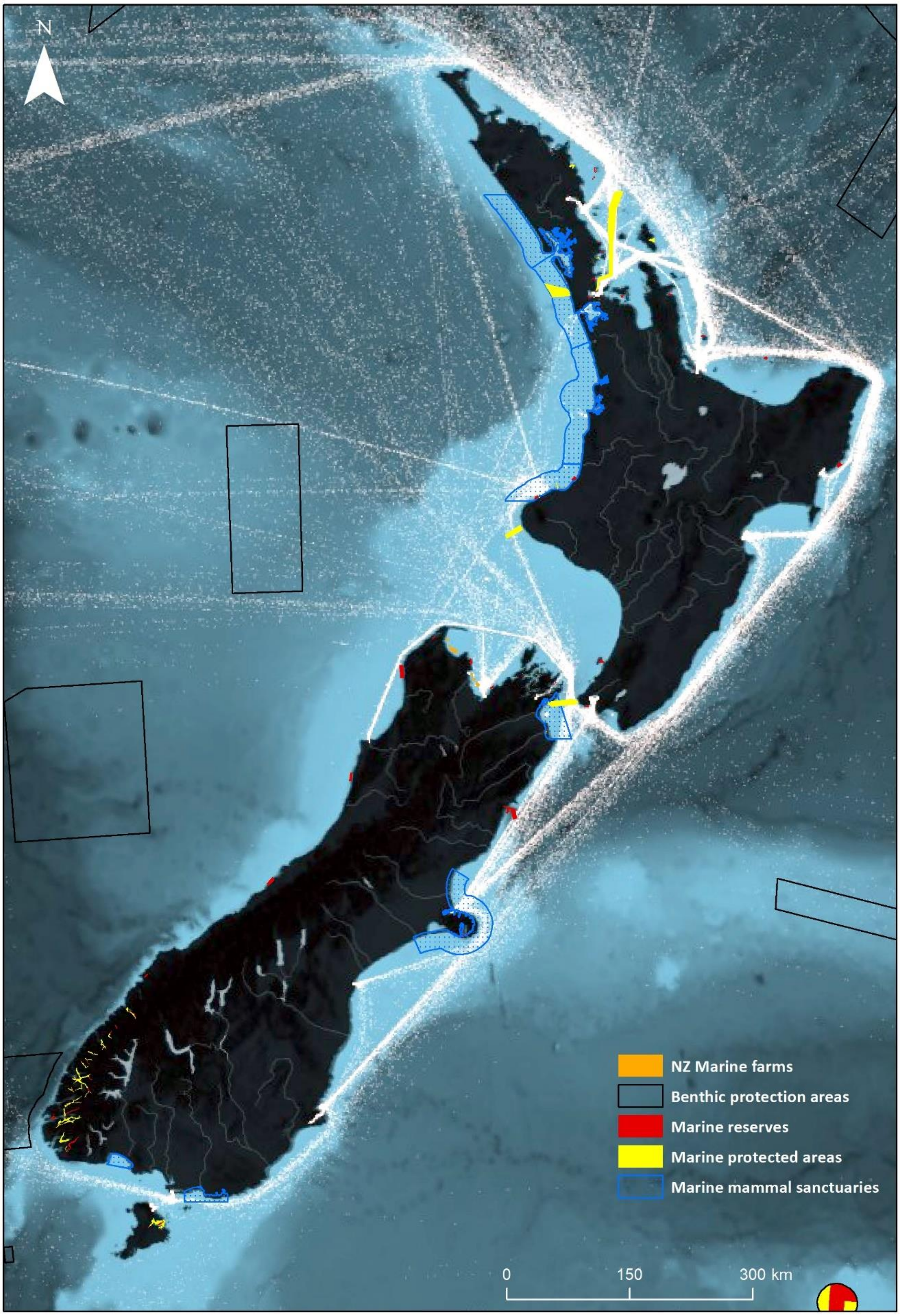


Figure 6-1: Location of shipping lanes and sensitive marine areas. Shipping lane visualisation based on data from 2012, downloaded from https://www.shipmap.org/

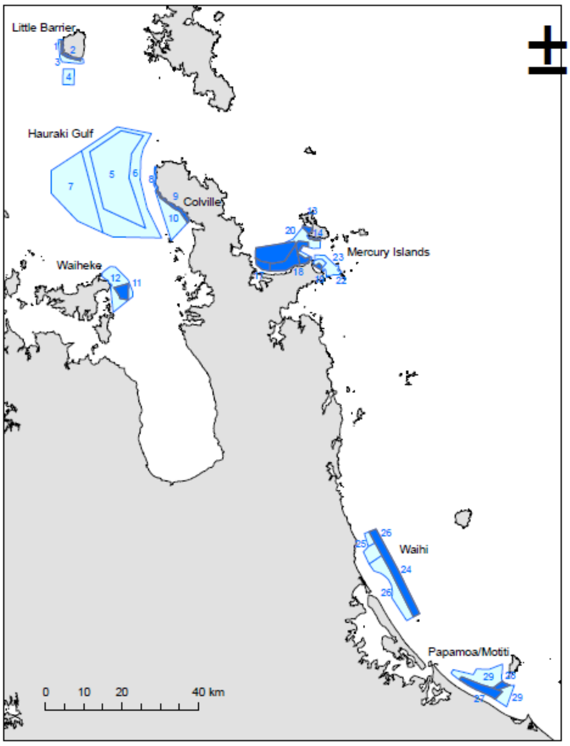


Figure 6-2: Locations surveyed for the Coromandel scallop stock assessment in 2012, which includes the locations of key scallop beds for commercial harvesting. Figure from (Williams et al. 2013).

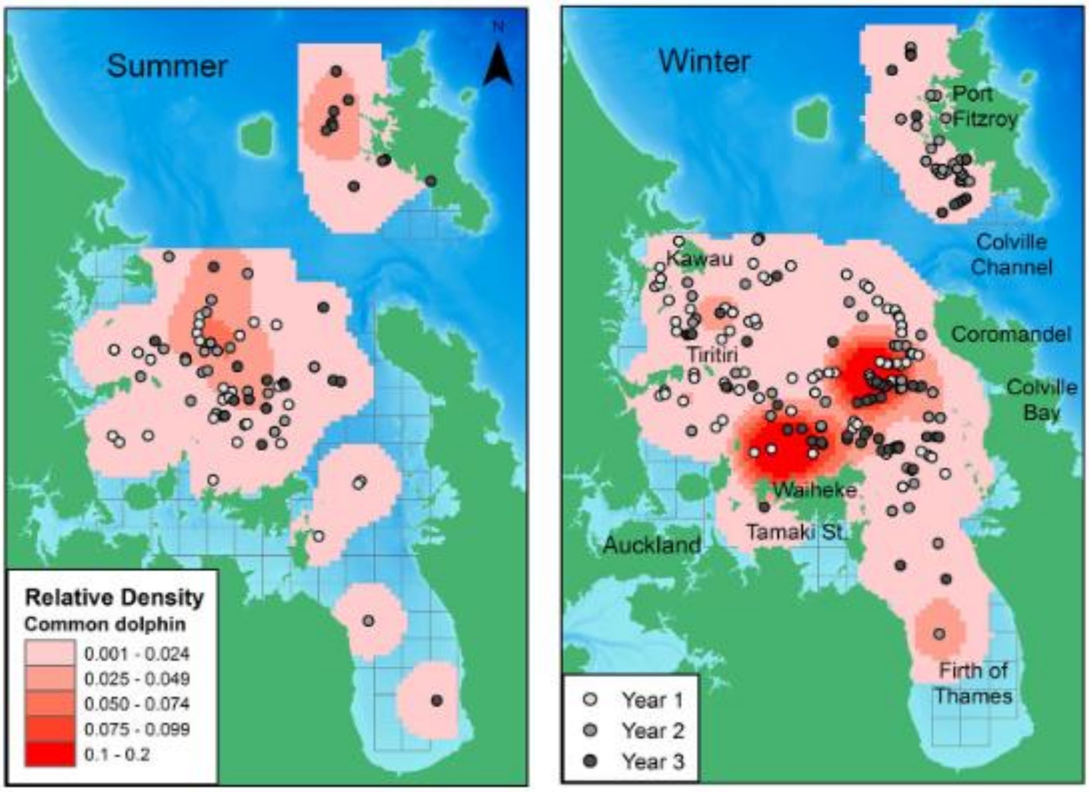


Figure 6-3: Seasonal relative densities of common dolphins in the inner Hauraki Gulf in 2010–2012 and off Great Barrier Island in 2011–2012. Darker shading represents higher density cells. The sighting position of each common dolphin group is indicated by a shaded grey dot according to year. Figure from Dwyer et al. (2016).

Cruise ships may be a further aspect that requires specific attention, as cruise ships travel to some locations that cargo vessels do not go to, and which may be areas of high ecological significance. This includes Milford Sound and other locations in Fiordland, which received over 100 visits by cruise ships in the 2018-2019 season (Table 6-1). There were also numerous visits to Akaroa Harbour and the Bay of Islands, which are not ports visited by other large vessels and are areas with either marine mammal sanctuaries or significant ecological areas.

Table 6-1: Top 15 locations in New Zealand visited by cruise ships between July 2018 and June 2019. Information from New Zealand Cruise Association cruise ship schedule[9].

Location	Number of ships visiting
Auckland	127
Fiordland	116
Tauranga	113
Wellington	109
Port Chalmers	103
Akaroa	91
Napier	74
Bay of Islands	66
Picton	46
Gisborne	19
Lyttelton	17
Stewart Island	17
Dunedin	11
Kaikoura	9
Nelson	8

[9] https://newzealandcruiseassociation.com/cruise-ship-schedule-2018-19/

7 Review of international risk assessments for scrubbers

7.1 Introduction

There are a number of international studies where the effects of scrubber discharges have been assessed, typically based on measurements of contaminants in the discharges and on pH. Most studies have assessed the discharges in terms of the hazards that they pose to the environment based on the contaminant concentrations, while only four have attempted to undertake a complete risk assessment incorporating exposure assessment.

7.2 Hazard and impact assessments

Studies in this section did not undertake a full risk assessment but did investigate the quality of washwater discharges and assess potential effects or hazards based on comparisons to water quality guidelines, either before or after dilution.

Niemi et al. (2006)

Niemi et al. (2006) undertook an assessment of the environmental effects of scrubbers in the Baltic Sea region for Wärtsilä and assessed the likely emissions without scrubbers. The full assessment was not provided in the document reviewed as it is a shorter public version of a confidential report. The assessment was based on contaminants in the exhaust gas, information on the maritime traffic in the region including vessel numbers, ship types, duration of port visits, engine power and energy usage. Emissions were based on a simplified methods for an “average ship” with a main engine (ME) of 10 MW (equating to a medium-sized ship), and four auxiliary engines (AE) of 1.5 MW each, with differing load factors for operation at sea (ME 80%, AE 30%), at berth (ME 20%, AE 40%), and manoeuvring (ME 20%, AE 50%). The study assessed emissions from three different scrubber types against environmental quality standards. They concluded that use of scrubbers would reduce the emissions to air and that in most cases the effluent would be able to meet environmental quality standard. The exception was within ports when using an open loop scrubber, where nickel concentrations may exceed standards.

US EPA

The US EPA study (US EPA 2011) included assessing the discharge quality from three vessels with prototype scrubbers: MS Zaandam, Pride of Kent and the MT Suula. Multiple samples were taken under differing conditions of vessel power and scrubber type. The quality of the discharges was compared to the IMO guidelines and to US EPA’s national water quality criteria, assessing the dilution rates required to meet these. It concluded that metals and PAHs have the potential to cause adverse effects, that pH is likely to be neutralised in the system and that nitrate and COD are unlikely to be of concern.

German UBA Study (Lange 2015)

A German study (Lange 2015) assessed the potential impacts on ports and coastal waters using data from previous studies of discharges from the MS Fjordshell, MS Pride of Kent and MS Ficaria Seaways. Discharge rates were estimated for four different example ships (tanker, feeder container ship, cruise and RoPax) based on their likely speed and power output, and a representative discharge rate of 50 m^3/MW/hr from open-loop systems and 0.1 m^3/MW/hr from closed-loop systems. Contaminant discharge loads were estimated for each ship for each of 6 selected routes, which indicated that open-loop systems had much higher discharge loads.

A qualitative impact assessment was undertaken, which outlined the key hazards from scrubber washwaters as reductions in pH, temperature rises, increases in turbidity and increases in pollutants including PAHs. The authors stated that a quantitative assessment would require modelling of the expected amounts of washwater from ship operations, along with waterbodies, tide, season and other environmental parameters. Furthermore, they stated that the German coastal waters were already under pressure from contaminants and in some locations in poor condition, and that the use of scrubbers in these waters would add to the pressure and was not consistent with the precautionary principle (Lange 2015).

CE Delft Economic and Environmental Assessment

The environmental assessment of scrubber use (den Boer & 't Hoen 2015) was a review of existing information with no further assessment undertaken. They reviewed the quality of washwater discharges from previous studies of the MV Ficaria Seaways (Kjølholt et al. 2012), MS Zaandam (US EPA 2011), MT Suula (Wärtisilä 2010) and Pride of Kent (Hufnagl et al. 2005). The assessment noted that the discharge quality exceeded environmental quality standards and that some studies showed these standards were met after dilution, and also noted that further assessment would be required for coastal areas and ports.

German BSH Study

The Federal Maritime and Hydrographic Agency (BSH) of Germany reported an interim assessment of effects on marine environments from scrubber washwaters (BSH 2018), based on analysis of samples from 5 ships and two scenarios: the current scenario (based on 81 ships having scrubbers and using the North Sea and Baltic Sea waters) and a maximum scenario based on all vessels with scrubbers. Dilution and dispersion of the washwaters was not considered in this assessment. Instead, a total load of contaminants was calculated and compared to other contaminant sources. The assessments assumed washwater discharges of 100 m^3/MW/hr from open-loop systems and 0.2 m^3/MW/hr from closed-loop systems. The total load from these discharges was compared to estimated inputs from other sources, including the Rhine River. Nitrate-N inputs from the Rhine were well in excess of the washwater discharges, however under the maximum scenario estimated inputs of PAHs from the washwater exceeded those estimated from other sources.

British Columbia, Whale waters

The ICCT (Georgeff et al. 2019) assessed potential effects from discharge of washwater from EGCS by ships operating in the North American Emission Control Area (ECA) off the coast of British Columbia, Canada, including in and near critical habitat for threatened and critically endangered orca, or resident killer whales (RKWs). They considered three scenarios: (1) status quo based on actual 2017 ship traffic and publicly available information on scrubber use[10] which indicated 30 vessels with scrubbers, mainly cruise ships; (2) year 2020 based on predicted EGCS uptake, with an estimate of 250 vessels with scrubbers, mainly bulk carriers ; and (3) an extreme scenario where all ships in the waters (2,359 vessels, mainly bulk carriers) use open-loop EGCS. They used an estimate of 45 m^3/MW/hr to estimate the total discharge volume from washwater, mapped based on AIS information. Based on this assessment, they concluded that the metals and PAHs from vessel discharges were a potential threat in marine mammal critical habitats (Georgeff et al. 2019).

[10] One of these information sources was a survey by Alaska Division of Water which contained information on EGCS from 37 vessels, apparently all cruise vessels. This information is downloadable at https://kcaw-org.s3.amazonaws.com/wp-content/uploads/2019/04/Additional-Obs-reports.zip

7.3 Risk assessments

The risks from scrubber discharges have been assessed in five studies internationally, with mixed results. The general methods and overall findings of the assessments are described below.

Danish EPA

The Danish EPA (Kjølholt et al. 2012) conducted a risk assessment for scrubber used based on three shipping scenarios (all ships > 2,000 tons using scrubbers, one ship with a 20 MW engine using a scrubber, and no ships using scrubbers) and two different areas of the Baltic Sea (the Kattegat area and the Aarhus Bight). Ship traffic intensity was obtained from AIS data in terms of the nautical miles sailed by ships classified into 5 key categories. The average size of engine (in MW) was estimated for each of the 5 ship categories based on the ship size (as tonnage, DWT). Maximum contaminant concentrations from the study of the "Ficaria Seaways" vessel washwater effluent were used in the assessment, with the exception of sulfur, which was based on the sulfur content in fuels assuming 100% trapping by the scrubber. Dilution and dispersion of the emissions in each water body was estimated based on previous studies of mixing providing a residence time and average discharge from that waterbody. Based on that assessment, after mixing, almost all hazardous substances were expected to be found at concentrations 3-6 orders of magnitude lower than the environmental quality standards, with the exception of copper and nickel, which were predicted to be about 100x lower than the environmental quality standard. A 'worst-case' scenario, based on revised factors for factors in the assessment would result in concentrations 12x higher than predicted – still well below environmental quality standards.

The use of scrubbers in ports was also considered, on the basis that ships use auxiliary engines in port, which may also be connected to scrubbers to reduce in-port air emissions. The total discharge from the scrubbers (based on 10 vessels at port at once) was estimated at 17,000 m^3/day, which would allow a dilution factor of 1,200 after complete mixing. Complete mixing was considered unlikely and this was therefore considered an area of uncertainty (Kjølholt et al. 2012).

Sweden

The Swedish Environmental Research Institute Ltd, IVL, conducted a study on scrubbers that included analysis of effects on air, water, toxicity testing, risk assessment, a cost-benefit analysis and a life-cycle analysis (Winnes et al. 2018). The risk assessment (Magnusson et al. 2018) was conducted with two different approaches: the first based on the chemical analyses of discharges from three ships (one RoPax and two RoRo cargo with either open-loop or closed-loop systems) and the second based on data from toxicity tests undertaken on those same discharges. Discharge rates were 0.0028 m^3/s for the two ships with closed-loop scrubbers and 0.097 m^3/s for the open-loop scrubber. Dilution rates in the mixing zone estimated from an equation based on ship size and speed and the discharge rates (Equation 5–1) were estimated at 16,000 for the vessel with open-loop scrubber and 530,000 and 670,000 for closed-loop scrubber vessels. For the risk assessment based on chemical analysis, the concentrations after dilution were less than the environmental quality standards by 3-6 orders of magnitude. However, when based on the toxicity test, the concentrations of the discharges were well below the lowest toxic dilution concentrations calculated in the toxicity tests but not below the thresholds calculated from those lowest toxic dilutions with a safety factor of 1000 following approaches used by the European Commission in deriving environmental quality standards.

The risk assessment (Magnusson et al. 2018) concluded that to adequately understand the risks, advanced modelled was required, including consideration of discharges from more than one vessel at a time (as conducted in this study), and discharges of pollutants from other sources (i.e., cumulative effects).

Japan

An expert board of researchers conducted an environmental impact assessment for the Ministries of Land, Infrastructure, Transport and Tourism; Environment and Agriculture, Forestry and Fisheries (Koyama et al. 2018). This assessment included:

- computational fluid dynamics (CFD) modelling of the dispersion and dilution of washwater discharged from a moving ship;
- toxicity testing of scrubber washwater samples collected from an experimental scrubber system;
- targeted chemical analysis of PAHs and metals and comparison of results to land-based discharge criteria in the Japanese Water Pollution Prevention Act;
- long-term simulation of pH and nitrate-N, phosphorus and COD concentrations in three enclosed harbours or coastal areas that included ports and shipping lanes (Tokyo Bay, Ise Bay and Seto Inland Sea) based on the number of ships, assuming all were using scrubbers, and using the simple model MAMPEC 3.1 to predict concentrations once mixed. It is not clear how the pH was modelled in MAMPEC as this does not model pH explicitly, and it may have been undertaken as simple dilution.

The conclusions, based on these above aspects, were that the risks to marine environments and marine organisms were in the acceptable range, and when considering the actual number of vessels with open-loop scrubbers, likely to be negligible.

Belgian waters

The most recent assessment was a recently published (July 2020) paper assessing the impact of scrubber discharges on water quality in the Antwerp (Belgium) harbour docks and in the Scheldt Estuary (Teuchies et al. 2020). This included additional analyses of washwater discharges from a hybrid scrubber (sampled operating in closed loop mode at berth and in open-loop mode in the estuary) and a second vessel with an open-loop scrubber (sampled at sea and when manoeuvring in the port of Antwerp). The study also compiled washwater discharge quality data from all available sources and provided these as a downloadable excel file (see Appendix A). The annual contaminant load from scrubbers was calculated for two scenarios: low, where 10% of vessels use scrubbers and high, where 20% of vessels use scrubbers. An average washwater discharge rate of 87 m^3/MWhr was used and the total engine output (power) for all vessels was provided by the port authority. Changes in the contaminant concentrations in the surface waters was calculated from the total contaminant input divided by the annual flow through the water body (L/yr), extrapolated from the mean flow rate.

The discharges were predicted to decrease pH by 0.015 units and increase the concentrations of individual PAH compounds by up to 200% and metals by <10%, except vanadium (~40%). For most metals and PAHs, the predicted concentrations would remain below the water quality standards, except nickel and zinc, which would exceed the standards under the high scenario, and fluoranthene, which exceeded the standard even in the absence of scrubbers.

Baltic ports

Faber et al. (2019) report on an assessment of the impact of scrubbers on water quality, conducted for the Cruise Lines International Association Europe, Interferry and the European Community Shipowners' Associations. Chemical analysis data were provided for 291 washwater samples from 53 different ships including cruise ships, bulk carriers and ferries; generally collected as required for monitoring in accordance with IMO regulations. Data were also supplied on the number of engines connected to the scrubber, the engines operating at the time of collection, engine load and fuel type. These data were used to calculate mean emission factors. The assessment used the MAMPEC-BW model (see section 5.4) to calculate predicted concentrations in four model ports: the standard OECD-EU commercial harbour (based on the Port of Rotterdam and defined as part of MAMPEC-BW model), Baltic commercial port, an ocean port and a river port. The increases in metals and PAHs in water (<0.6% increase) and sediment of each model port were predicted to be minor for most scenarios, but highly dependent on the hydrodynamic exchange rates of the port.

7.4 Summary

The hazard assessments reviewed generally found that there could be some potential risks from scrubber discharges based on comparisons of discharge quality to environmental standards, typically due to the metals and/or PAHs in the discharges. They identified that these risks would depend on the locations of discharges and the dilution rates, and that risks could be highest for coastal areas and ports.

Most studies that assessed risks after considering dilution predicted that contaminant concentrations would be orders of magnitude below water quality standards. Those studies that reported low risk assessed either moving vessels (in shipping lanes), assumed complete mixing of discharges within an estuary, or considered the discharge from a single vessel only. The high background concentrations of some contaminants in some locations also influenced the conclusions of one study that scrubbers had little effect on contaminant concentrations.

Several studies suggested that there was increased potential for adverse effects within ports, especially when there were multiple vessels, though only two studies adequately assessed this – and their conclusions differed. One study, assuming discharges from multiple vessels, found that increases in metals and PAHs would be low; whereas the other concluded that PAH concentrations would increase substantially.

8 A risk assessment for NZ – the path forward

8.1 Introduction

As described in the introduction to this report, an environmental risk assessment for the scrubber discharges needs to include an assessment of the hazards (including toxicity) posed and an assessment of the likely environmental concentrations. This information is combined to assess the risks. To date, few of the assessments undertaken overseas have included risks, with most assessing potential hazards. Several concluded that more information and more modelling was required to assess risks, particularly in locations that would pose higher risks: ports and estuaries.

8.2 Risk assessment scenarios

The risk assessment scenarios need to consider spatial and temporal considerations, and the range of representative values that could be used for the discharge and environmental parameters.

There is sufficient information (number of vessels at port or in the shipping lane; hydrodynamic models) available to undertake site-specific risk assessments, which would be more accurate than generic models. We recommended including a number of locations for the risk assessment, based on a range of vessel numbers and types; hydrodynamics and flushing rates; and ecological receptors. Some suggested locations are included in Table 8-1 based on a cursory review of information as presented in Section 7. This should be refined in Phase 2 as the first step of the risk assessment, after compilation of additional information on Te ao Māori perspectives, marine mammals, commercial fishing (including shellfish), aquaculture zones, seabird colonies and areas of significance for ecological or cultural reasons.

Table 8-1: Suggested locations for assessing risks of scrubber discharges.

Locations	Justification
Shipping lanes	
Mayor Island	Marine reserve
Poor Knights	Marine reserve
Hauraki Gulf	Marine park, area under pressure from multiple threats, also includes aquaculture and commercial fishing areas
Cook Strait	High vessel numbers
Ports and harbours	
Auckland	Major NZ port (high vessel numbers), multiple cumulative effects
Tauranga	Major NZ port (high vessel numbers), multiple cumulative effects
Whangarei	Major NZ port, proximity to commercial shellfish beds and areas of ecological significance
Lyttelton	Major NZ port; low hydrodynamic flushing compared to other NZ ports (Gadd et al. 2011)
Akaroa	Cruise ship visits, within a marine mammal sanctuary, distant from other stressors
Milford Sound	Cruise ship visits, within a marine protected area; pristine environment; distinctive physical environment (freshwater overlying seawater)

The temporal aspects of the risk assessment scenario to consider are the time period over which the assessment is averaged (e.g., daily, monthly or annual) and timing of the scenario (e.g., summer or winter). For example, vessel numbers show temporal variability, particularly for cruise ships which mainly visit over summer. Risk assessments should be conducted based on a particular time of year, rather than an annual average and should take into account expected increases in vessel numbers.

The risk assessment also needs to be conducted under plausible scenarios. These can include a typical scenario and a worst-case scenario. In many screening level assessments, a realistic worst-case scenario is used rather than a scenario that takes the worst-case options (e.g., highest discharge rate, maximum contaminant concentrations) for all aspects of the risk calculation, and is therefore highly unlikely to occur. A realistic worst-case might use 90th percentile concentrations for the discharge quality and maximum vessel numbers. A typical case would include the median or mean discharge quality and average vessel numbers.

8.3 Available information

Based on the information reviewed, there is sufficient data to conduct a quantitative risk assessment, either for New Zealand as a whole or for specific locations of interest such as those suggested in Table 8-1. Site-specific risk assessments would be more accurate and can be conducted using information on the number of vessels at the port or in the shipping lane, along with hydrodynamic models for that location.

As reviewed in this report, there are a number of factors to be considered in assessing the risks to marine environments from discharges of scrubber washwaters. These include:

- The number of vessels using scrubbers in any location at one time;
- The location of the vessels during discharges and the dilution and dispersion of the washwater discharges in those locations;
- The concentrations of contaminants in the discharge and the volume of discharge (which, as described in sections 3 and 5.3, depend on the type of scrubber, vessel type and engine load);
- Any particularly sensitive species present in those locations of interest;

Table 8-2 outlines the information that is required to undertake the risk assessment, for options of varying complexity. These differ in complexity from simple, screening level information to those requiring more detailed data and modelling. The simple methods, whilst requiring lower resources, are expected to have higher uncertainty than more detailed options.

The options shaded in green are the recommended options for the risk assessment. In most cases, these options are based on information that is either already available, or available with some further data analysis (e.g., vessel numbers) or literature review (e.g., bioconcentration factors); can be readily undertaken with MfE's preferred timeframe, and do not require highly specialist expertise. Two options are shaded for information on the number of vessels using scrubbers in New Zealand. MfE are requesting information from 10 nations regarding the use of scrubbers by vessels registered to them[11], however as those nations may not all provide the required information, we have included an alternative option here.

[11] Matt Adams, MfE.

Table 8-2: Information to use in risk assessments for options of varying complexity. Green shading indicates recommended options for a mid-tier risk assessment.

Factor to include in risk assessment	Information to use for risk assessment options of differing complexity and resource requirements		
	Option A	Option B	Option C
Locations of interest	1 x shipping lane, 1 x key port	2-3 shipping lanes, 2-3 ports, key cruise ship areas	Multiple ports, shipping lanes, and cruise ship areas
No. of vessels	Customs arrival data for each port	Customs arrival data and assumptions regarding route or Lloyds database information from 2016	Customs arrival data and assumptions regarding route or Lloyds database information from 2016
Vessel types	Based on averages for all of NZ	Based on Lloyds data from 2016 for each location of interest	Based on Lloyds data from 2016 for each location of interest
Number of vessels currently using scrubbers	Total vessels visiting NZ in each category x global proportion vessels with scrubbers in each category	Information from flag nations, or search IMO GISIS database for top 100 vessels visiting NZ	Search IMO GISIS database for all vessels visiting NZ
Number of vessels expected to use scrubbers in future	Assume 2-3x the number of vessels	Total vessels visiting NZ in each category, adjusted for increased growth in shipping x global proportion vessels with scrubbers in each category x 2-3 for increased scrubber uptake	
Discharge quality	Median and maximum (or 95th percentile) options from literature data	Median and maximum (or 95th percentile) options from literature data for different scrubbers	Median and maximum (or 95th percentile) options from literature data for different scrubbers, vessel types and engine loading
Discharge rates	**Rate = m^3 per MW x engine size x engine load**		
Discharge rate per MW	Based on literature data, as compiled in this report	Based on literature data, as compiled in this report	Based on literature data, as compiled in this report
Engine power	Average engine size per vessel category	Average engine size per vessel category & size from literature	Acquire engine size for actual vessels visiting NZ from Lloyds register or look up individual ships on sites such as balticshipping.com

Factor to include in risk assessment	Information to use for risk assessment options of differing complexity and resource requirements Option A	 Option B	 Option C
Loading rates	Assume 100% loading at all times	Average loading rates at port and at sea	Range of loading rates at port and at sea, dependent on vessel type
Calculation of concentrations after mixing	Dilution rates from vessel moving equations	MAMPEC models for ports and shipping lanes	Specific hydrodynamic models for harbours and/or key areas like Hauraki Gulf
pH assessment	Calculate from H^+ concs. dased on dilution	Use MAMPEC to calculate H^+ conc. then recalculate pH accounting for carbonate chemistry	Use implementations of carbonate chemistry in hydrodynamic models
Toxicity assessment for water column	Compare PECs to water quality guidelines	Compare PECs to water quality guidelines	Compare PECs to toxicity data for species of interest
Biota & sediment uptake	Exclude	Exclude	Calculate biota uptake from BCFs; and sediment uptake with Kd or MAMPEC
Toxicity assessment for sediment and biota	Exclude	Exclude	Compare calculated concentrations to sediment quality guidelines
Cumulative effects	Exclude	Include other discharges by increasing background concentrations in MAMPEC model	Add other point source discharges to hydrodynamic models

The recommended options above would provide a mid-tier level risk assessment which is less conservative and has less uncertainty than a screening level assessment. This tier is considered most suitable, as screening level assessments already undertaken internationally have generally recommended that further modelling is required for ports and harbours. Note that if a risk assessment based on the recommended options above is undertaken, and this indicates locations where risks are unacceptably high, then the more detailed options may be required to more accurately assess risks, for example, undertaking hydrodynamic modelling.

Note that simple dilution and dispersion models are not suitable to adequately assess pH which does not act conservatively in seawater. We therefore recommend using those dilution models to calculate concentrations of H^+ ions, then use these model outputs, along with information on background pH, and alkalinity (dissolved inorganic carbon) to recalculate the pH. Input data (pH, alkalinity and dissolved inorganic carbon) will be gathered from locations around New Zealand as monitored in the New Zealand Ocean Acidification Observing Network (NZOA-ON)[12], a network of 17 locations around New Zealand. A range of input data can be used to check the sensitivity to input values; and future scenarios could be included by starting with a lower background pH, accounting for ocean acidification.

8.4 Information gaps, limitations and assumptions

There are a number of data limitations and assumptions that need to be considered in undertaking a risk assessment in Phase 2 of this report. The major ones are outlined below:

- The most important information gap relates to the **number of scrubbers in use in New Zealand waters**, as this information is not readily available; at least not without devoting substantial resource (i.e., purchasing information from Lloyd's; or by looking up information for the 3890 unique vessels that arrived in New Zealand in 2017-2019). If information cannot be obtained from the flag nations for the majority of the vessels, the scrubber usage will need to be assumed based on international uptake or on the data obtained for a subset of vessels. This gap can be mitigated by modelling a number of scenarios for the likely number of vessels with scrubbers, including upper estimates.
- **Vessel engine power and loading** will need to be assumed, based on literature. This critical factor will affect the contaminant discharge loads by several factors as engine power varies nearly 100-fold between small vessels and large vessels; and the engine loading may vary by factor of two or more when at berth or manoeuvring. This gap can be mitigated by using an upper, conservative, estimate for the loading rate.
- Although there is information available for the **MAMPEC model** for 11 ports[13] around New Zealand, this does not include all ports that may be of interest for assessing scrubber discharges; and there are **no scenarios already established for shipping lanes** in New Zealand. Additional information will need to be assembled to develop scenarios for shipping lanes, including water quality data such as the concentrations of particulate matter and organic carbon. It is likely that this information will not exist for the specific locations of interest and data from nearby locations will need to be used. This limitation is readily addressed through additional resourcing to set up these scenarios.
- The **contaminant concentrations in the scrubber discharges** range over orders of magnitude for some contaminants, depending on the vessel, scrubber type and engine power. The concentrations selected for use in the risk assessment are likely to have considerable influence on the outcomes of that assessment. At the very least, the different scrubber types should be considered separately as the discharge concentrations and rates vary substantially between closed-loop and open-loop systems. Median and upper estimates (e.g., 95th percentile) should be used for the modelling to understand the effect of scrubber discharge concentrations on the risk assessments.

[12] https://marinedata.niwa.co.nz/nzoa-on/

[13] Northport, Whangarei; Port of Auckland; Port of Onehunga; Tauranga; Napier; Wellington; Picton; Nelson; Lyttelton; Port Chalmers, Dunedin and Freshwater Basin, Milford Sound. See Gadd et al. (2011).

- There are some **contaminants for which there is little to no information** regarding their presence in the scrubber discharges. This includes rare earth elements and alkylated PAHs. There is also limited toxicity data for many of these substances. This gap could be addressed by predicting indicative concentrations in the discharges based on concentrations in the fuel oils, relative to vanadium; and investigating literature for toxicity studies.

- Water quality guidelines for the **rare earth elements** are not available and the guideline for **vanadium** is of moderate reliability based on limited marine chronic toxicity tests. The environmental fate of vanadium is not well-known (Watt et al. 2018) including partitioning and bioaccumulation. Recent studies suggest it may be more toxic to the larval life-stage of marine invertebrates (including cockles and urchins) than to adult organisms, with effects on development occurring at 50-100 µg/L (Fichet & Miramand 1998). Similarly, the likelihood for **TPH** residues on the ocean surface is not easily predicted, nor would the effects be easily assessed.

- **Bioaccumulation and biomagnification will only be considered in a simplistic manner**. If the assessment suggests that there are potential effects through bioaccumulation and consumption of shellfish and fish, a higher tier assessment may be required and that has not been scoped here.

- The **cumulative effects** of the scrubber discharges may need more detailed consideration, including the effects on pH in a climate of increasing ocean acidification.

While many of the gaps listed above can be mitigated through use of upper estimates, the effect of using multiple upper estimates also needs to be considered, as this may result in an unrealistic scenario, and/or many multiple scenarios to be modelled. One approach to addressing these limitations is to use “base” estimates for all locations of interest and use a range of estimates for a single location to assess the sensitivity of the risk assessment findings to these model inputs.

9 Acknowledgements

We acknowledge the assistance of multiple NIWA colleagues for this assessment including: Greg Olsen, in compiling the discharge quality data and providing input regarding the measurement of PAHs; Kimberley Seaward in providing the table of vessel data sources and the figure of sensitive marine areas and shipping lanes; Kim Currie for useful discussions and advice around pH modelling, and Glen Reeve and Niall Broekhuizen for information on hydrodynamic models available in New Zealand.

10 References

ABS (2017). ABS advisory on exhaust gas scrubber systems. ABS American Bureau of Shipping. Houston, Texas. 48 p.

Ahrens, M.J.; Nieuwenhuis, R.; Hickey, C.W. (2002). Sensitivity of juvenile Macomona liliana (bivalvia) to UV-photoactivated fluoranthene toxicity. Environmental Toxicology 17(6): 567-577.

ANZECC (2000). Australian and New Zealand guidelines for fresh and marine water quality. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand Volume 1: The guidelines. p.

ANZG. (2018). Australian and New Zealand guidelines for fresh and marine water quality. from https://www.waterquality.gov.au/anz-guidelines/

ANZG (2020). Toxicant default guideline values for aquatic ecosystem protection Zincin marinewater Technical brief. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. CC BY 4.0. Australian and New Zealand Governments and Australian state and territory governments. June 2020. Canberra, ACT, Australia. 24 p.

Aulinger, A.; Matthias, V.; Zeretzke, M.; Bieser, J.; Quante, M.; Backes, A. (2016). The impact of shipping emissions on air pollution in the greater North Sea region – Part 1: Current emissions and concentrations. Atmos. Chem. Phys. 16(2): 739-758.

Beatty, J.M.; Russo, G.A. (2014). Ambient water quality guidelines for Selenium. Technical Report Update. Water Protection and Sustainability Branch, Environmental Sustainability and Strategic Policy Division, British Columbia Ministry of Environment. April 2014. British Columbia, Canada. 270 p.

Browning, L. (2009). Current methodologies in preparing mobile source port-related emission inventories. Final report. ICF International, Prepared for U.S. Environmental Protection Agency. April 2009. Virginia, USA. 116 p.

BSH (2018). Chemical characterization of discharge water from exhaust gas cleaning systems (EGCS) and a first estimate of total discharges to the North Sea, the Baltic Sea and the English Channel. IMO IMO Sub-Committee On Pollution Prevention And Response 6th session Agenda item 11. Review of the 2015 guidelines for exhaust gas cleaning systems (resolution MEPC.259(68)). Results from a German project on washwater from exhaust gas cleaning systems. Submitted by Germany. PPR6 / INF.20. 14 December 2018. p.

Buhaug, Ø.; Fløgstad, H.; Bakke, T. (2006). MARULS WP3: Washwater Criteria for seawater exhaust gas-SOx scrubbers. MARINTEK, SINTEF and NIVA. 260001.30.01. October 2006. Annex I of Marine Environment Protection Committee 56th session MEPC 56/INF.5 Submitted by the United States. 39 p.

CCME. (1999a). Canadian sediment quality guidelines for the protection of aquatic life: Arsenic. In: Canadian environmental quality guidelines, 1999, pp. Canadian Council of Ministers of the Environment, Winnipeg, Canada.

CCME. (1999b). Canadian soil quality guidelines for the protection of environmental and human health: Vanadium (1997). In: Canadian environmental quality guidelines, 1999, pp. Canadian Council of Ministers of the Environment, Winnipeg, Canada.

CCME. (1999c). Canadian water quality guidelines for the protection of aquatic life: pH (marine). In: Canadian environmental quality guidelines, 1999, pp. 3. Canadian Council of Ministers of the Environment, Winnipeg, Canada.

Clearwater, S.J. (2009). Ecotoxicity information on species cultured at NIWA Bream Bay Aquaculture Park. Report for Whangarei District Council NIWA client report HAM2009-113. NIWA, Hamilton. 39 p.

De Meyer, P.; Maes, F.; Volckaert, A. (2008). Emissions from international shipping in the Belgian part of the North Sea and the Belgian seaports. Atmospheric Environment 42(1): 196-206.

den Boer, E.; 't Hoen, M. (2015). Scrubbers – An economic and ecological assessment. Delft, CE Delft. Publication code: 15.4F41.20. March 2015. CE Delft, Delft, The Netherlands. 45 p.

Dudley, B.D.; Plew, D.; Whitehead , A.; Zeldis, J. (2019). Canterbury coastal and harbour water quality investigation. NIWA Client Report, 2019053CH. Report to Canterbury Regional Council. 51 pp. p.

Dwyer, S.L.; Clement, D.M.; Pawley, M.D.M.; Stockin, K.A. (2016). Distribution and relative density of cetaceans in the Hauraki Gulf, New Zealand. New Zealand Journal of Marine and Freshwater Research 50(3): 457-480.

EGCSA and Euroshore (2018). Report on analyses of water samples from Exhaust Gas Cleaning Systems. Exhaust Gas Cleaning Systems Association and Euroshore Sustainable Ship Waste Solutions. 35 p.

Faber, J.; Hattum, B.v.; Kleissen, F. (2019). The impacts of EGCS washwater discharges on port water and sediment. CE Delft Publication code: 19.4I09.141. October 2019. Delft, the Netherlands. 62 p.

Fichet, D.; Miramand, P. (1998). Vanadium toxicity to three marine invertebrates larvae: Crassostrea gigas, Paracentrotus lividus and Artemia salina. Chemosphere 37(7): 1363-1368.

Gadd, J.; Depree, C.; Hickey, C.W. (2011). Relevance to New Zealand of the OECD emission scenario document for antifouling products: Phase 2 report. NIWA Client Report HAM2011-005. August 2011. Hamilton. p.

Georgeff, E.; Mao, X.; Comer, B. (2019). A whale of a problem? Heavy fuel oil, exhaust gas cleaning systems, and British Columbia's resident killer whales. ICCT ICCT consulting report. ICCT, T.I.C.o.C.T., 27 p.

Gregory, D. (2012). A practical guide to exhaust gas cleaning systems for the maritime industry. EGCSA Handbook 2012. Sustainable Maritime Solutions Ltd. United Kingdom. 145 p.

Hansen, J.P. (2012). Exhaust gas scrubber installed onboard MV Ficaria Seaways. Environmental Protection Agency, Danish Ministry of the Environment Environmental Project No. 1429 Environmental Project No. 1429. Denmark. 31 p.

Herrmann, H.; Nolde, J.; Berger, S.; Heise, S. (2016). Aquatic ecotoxicity of lanthanum – A review and an attempt to derive water and sediment quality criteria. Ecotoxicology and Environmental Safety 124: 213-238.

Hufnagl, M.; Liebezeit, G.; Behrends, B. (2005). Effects of Sea Water Scrubbing Final report. BP-Marine and Terramare. Wilhelmshaven, Germany. 144 p.

IARC. (2019). IARC Monographs on the Evaluation of Risk to Humans. International Agency for Research on Cancer, World Health Organisation. Retrieved 08/08/2019, 2019

IMO Secretariat. (2015). Resolution MEPC.259(68) – 2015 Guidelines For Exhaust Gas Cleaning Systems. Committee, Session, May 2015. Document Number, Marine Environment Protection Committee, IMO, 25 p.

IMO Secretariat. (2020). Air Pollution Prevention. Preliminary overview of data on fuel oil quality and availability currently in the MARPOL Annex VI module in GISIS. Committee, Session, July 2020. Document Number, Marine Environment Protection Committee, IMO, 10 p.

IPCS (2010). WHO human health risk assessment toolkit: chemical hazards. World Health Organization, the International Labour Organization and the United Nations Environment Programme IPCS harmonization project document; no.8. Geneva, Switzerland. p.

Jalkanen, J.P.; Brink, A.; Kalli, J.; Pettersson, H.; Kukkonen, J.; Stipa, T. (2009). A modelling system for the exhaust emissions of marine traffic and its application in the Baltic Sea area. Atmos. Chem. Phys. 9(23): 9209-9223.

Kjølholt, J.; Aakre, S.; Jurgensen, C.; Lauridsen, J. (2012). Assessment of possible impacts of scrubber water discharges on the marine environment. Environmental Protection Agency, Danish Ministry of the Environment Environmental Project No. 1431 Environmental Project No. 1431. Lyngby, Denmark. 93 p.

Koski, M.; Stedmon, C.; Trapp, S. (2017). Ecological effects of scrubber water discharge on coastal plankton: Potential synergistic effects of contaminants reduce survival and feeding of the copepod Acartia tonsa. Marine Environmental Research 129: 374-385.

Koyama, J.; Ishimaru, T.; Takasaki, K.; Takahashi, C.; Matsumoto, T.; Michio, Y.; Yamaji, K. (2018). Report by the expert board for the environmental impact assessment of discharge water from scrubbers (Japan). July 2018. 71 p.

Lange, B. (2015). Impacts of scrubbers on the environmental situation in ports and coastal waters. July 2015. Umweltbundesamt, Dessau-Roßlau, Germany. 84 p.

Lewis, C.; Ellis, R.P.; Vernon, E.; Elliot, K.; Newbatt, S.; Wilson, R.W. (2016). Ocean acidification increases copper toxicity differentially in two key marine invertebrates with distinct acid-base responses. Scientific Reports 6(1): 21554.

Linders, J.; Adams, E.; Behrends, B.; Dock, A.; Hanayama, S.; Luit, R.; Rouleau, C.; Tronczynski, J. (2019). Exhaust gas cleaning systems. A Roadmap to Risk Assessment. Advice to the Marine Environment Protection Committee and its Sub-Committee on Pollution Prevention and Response. GESAMP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection Annex Report Of The Gesamp Task Team On Exhaust Gas Cleaning Systems PPR 7/INF.23. December 2019. 123 p.

MacMillan, G.A.; Chételat, J.; Heath, J.P.; Mickpegak, R.; Amyot, M. (2017). Rare earth elements in freshwater, marine, and terrestrial ecosystems in the eastern Canadian Arctic. Environmental Science: Processes & Impacts 19(10): 1336-1345.

Magnusson, K.; Thor, P.; Granberg, M. (2018). Scrubbers: Closing the loop. Activity 3: Task 2. Risk assessment of marine exhaust gas scrubber water. IVL Swedish Environmental Research Institute Ltd. No. B 2319. December 2018. Stockholm, Sweden. 50 p.

Millero, F.J.; Woosley, R.; Ditrolio, B.; Waters, J. (2009). Effect of ocean acidification on the speciation of metals in seawater. Oceanography 22(4): 72-85.

Niemi, S.; Mäkelä, K.; Hänninen, S.; Haahti, H.; Kankaanpää, H.; Mäkelä, K. (2006). Environmental effects of caustic soda and sea water scrubbers. Report for Wärtsilä Finland Oy. VTT and FIMR. VTT-R-08868-06. 23 November 2006. Annex II of Marine Environment Protection Committee 56th session MEPC 56/INF.5 Submitted by the United States. 39 p.

NIWA. (undated). North Island tidal currents. NIWA. Retrieved 8 September 2020, 2020, from https://niwa.co.nz/our-science/coasts/research-projects/all/physical-hazards-affecting-coastal-margins-and-the-continental-shelf/news/northis

Saraogi, V. (2020). Debunking: the problem of ships using open-loop scrubbers. Retrieved 7/08/2020, 2020, from https://www.ship-technology.com/features/open-loop-scubbers/

Teuchies, J.; Cox, T.J.S.; Van Itterbeeck, K.; Meysman, F.J.R.; Blust, R. (2020). The impact of scrubber discharge on the water quality in estuaries and ports. Environmental Sciences Europe 32(1): 103.

Tzannatos, E. (2010). Ship emissions and their externalities for the port of Piraeus – Greece. Atmospheric Environment 44: 400-407.

US EPA (1986). Quality criteria for water (gold book). United States Environmental Protection Agency, Criteria and Standards Division. EPA 440/5-86-001. US EPA, Washington D.C. 395 p.

US EPA (1996). 1995 Updates: Water quality criteria documents for the protection of aquatic life in ambient water. United States Environmental Protection Agency, Office of Water. EPA 820-B 96-001. September 1996. Washington D.C. 114 p.

US EPA (2011). Exhaust Gas Scrubber Washwater Effluent. United States Environmental Protection Agency Office of Wastewater Management. EPA-800-R-11-006. November 2011. Washington, DC. 42 p.

US EPA. (2019a). Conducting a Human Health Risk Assessment. from https://www.epa.gov/risk/conducting-human-health-risk-assessment

US EPA. (2019b). IRIS Assessments. United States Environmental Protection Agency,. Integrated Risk Information System

Wärtisilä (2010). Exhaust gas scrubber installed onboard MT "SUULA" : public test report. p.

Wärtisilä (2014). Exhaust gas cleaning. How to choose the correct scrubber. Wärtisilä Moss Business White Paper. Wärtisilä, Helsinki, Finland. 8 p.

Watt, J.A.J.; Burke, I.T.; Edwards, R.A.; Malcolm, H.M.; Mayes, W.M.; Olszewska, J.P.; Pan, G.; Graham, M.C.; Heal, K.V.; Rose, N.L.; Turner, S.D.; Spears, B.M. (2018). Vanadium: A Re-Emerging Environmental Hazard. Environ Sci Technol 52(21): 11973-11974.

Whall, C.; Cooper, D.; Archer, K.; Twigger, L.; Thurston, N.; Ockwell, D.; McIntyre, A.; Ritchie, A. (2002). Quantification of emissions from ships associated with ship movements between ports in the European Community. Final Report. Entec UK Ltd. July 2002. Cheshire, England. 80 p.

Williams, J.R.; Parkinson, D.M.; Bian, R. (2013). Biomass survey and yield calculation for the Coromandel commercial scallop fishery, 2012. Ministry for Primary Industries New Zealand Fisheries Assessment Report 2013/18. Wellington. p.

Winnes, H.; Granberg, M.; Magnusson, K.; Malmaeus, M.; Mellin, A.; Stripple, H.; Yaramenka, K.; Zhang, Y. (2018). Scrubbers: Closing the loop. Activity 3: Summary. Environmental analysis of marine exhaust gas scrubbers on two Stena Line ships. IVL Swedish Environmental Research Institute Ltd. December 2018. Stockholm, Sweden. 19 p.

World Maritime Affairs (2019). Ship Exhaust Scrubber system : What is all about ? p.

Yasnygina, T.; Malykh, Y.; Rasskazov, S.; Primina, S.; Zemskaya, T.; Khlystov, O. (2006). The ICP-MS determination of rare earths and other metals in Baikal crude oil: Comparison with crude oils in Siberia and the Russian Far East. Doklady Earth Sciences 411: 1237-1240.

Ytreberg, E.; Hassellöv, I.-M.; Nylund, A.T.; Hedblom, M.; Al-Handal, A.Y.; Wulff, A. (2019). Effects of scrubber washwater discharge on microplankton in the Baltic Sea. Marine Pollution Bulletin 145: 316-324.

Zeldis, J.; Whitehead, A.; Plew, D.; Madarasz-Smith, A.; Oliver, M.; Stevens, L.M.; Robertson, B.; Storey, R.; Burge, O.; Dudley, B. (2017). The New Zealand Estuary Trophic Index (ETI) Tools: Web Tool 1 - Determining Eutrophication Susceptibility using Physical and Nutrient Load Data. Ministry of Business, Innovation and Employment Envirolink Tools Contract: C01X1420

Appendix A Washwater discharge quality

Table A-1: General inorganic contaminants (mg/L) in scrubber washwater discharges.

Ship name	Scrubber mode	pH	SS	Turbidity (FNU)	COD	Total sulfur	Total nitrogen	Reference
MV Ficaria Seaways	Open-loop, sea water	3.7	14	-	52	900	0.56	Kjolholt et al. (2012)
		5.2	10	-	56	900	0.34	Kjolholt et al. (2012)
		5.5	15	-	48	890	0.36	Kjolholt et al. (2012)
		5.8	12	-	46	870	0.22	Kjolholt et al. (2012)
	Closed-loop, fresh water	5.9	91	-	450	1800	24	Kjolholt et al. (2012)
		6.5	350	-	1000	6400	120	Kjolholt et al. (2012)
		-	25	-	440	9000	120	Kjolholt et al. (2012)
		6.2	85	-	30	1500	25	Kjolholt et al. (2012)
		7.0	220	-	800	4500	55	Kjolholt et al. (2012)
		-	39	-	490	4800	86	Kjolholt et al. (2012)
MV Ficaria Seaways	Open-loop, sea water	3-6	2.8	-	-	-	0.13	Hansen et al. (2012)[2]
MV Fjordshell	Open-loop, seawater	3.0	0.68[1]	-	33	-	-	Lange et al. (2015)
MS Zaandam	Open-loop seawater	5.4-6.3	17	8	130	-	0.05	USEPA (2011)
Pride of Kent	Open-loop seawater	2.7-3.8		-	-	870-1020[3]	215	Hufnagl (2005); USEPA (2011)
MT Suula	Closed-loop freshwater	7.65		0.5	-	-	450[4]	USEPA (2011)
Japanese model	Open-loop	3.0		13.6	-	-	-	Koyama et al. (2018)
Stena Britannica	Closed-loop	7.6		9.3	-	19,000	49	Magnuson et al. (2018)
Stena Transporter	Closed-loop	6.9		12.9	-	22,000	-	Magnuson et al. (2018)
Stena Forerunner	Open-loop	-		2.5	-	1,200	-	Magnuson et al. (2018)
Ships 1,2,3,4,5	Open-loop	2.8-5.5		4.5-17.3	-	164-822[3]	<DL – 0.8[4]	BSH (2018)
Ships 1,2,4,5	Closed-loop	3.6-7.1		4.6-39.4	-	8,250-21,710[3]	11-144[4]	BSH (2018)
Unknown ship 1	Hybrid closed-loop	3.5-8.2		-	-	-	-	Teuchies et al. (2020)
Unknown ship 1	Hybrid open-loop	3.8-5.6		-	-	-	-	Teuchies et al. (2020)
Unknown ship 2	Open-loop	5.9-6.6		-	-	-	-	Teuchies et al. (2020)

[1] Calculated as particles plus soot.
[2] Different study on the same ship.
[3] Calculated from Total sulphate in discharge water
[4] Calculated as NO_3-N concentration (not normalized)

Table A-2: Metal concentrations in scrubber washwater discharges. All metals measured in µg/L.

Ship name	As	Cd	Cr	Cu	Hg	Pb	Ni	V	Zn	Reference
MV Ficaria Seaways	<1	<0.2	-	260	0.086	21	43	180	450	Kjolholt et al. (2012)
	1.8	<0.2	-	150	0.092	3.6	20	81	150	Kjolholt et al. (2012)
	<1.0	<0.2	-	110	0.099	5.8	19	49	110	Kjolholt et al. (2012)
	<1.0	<0.2	-	150	0.064	3.8	9.1	25	98	Kjolholt et al. (2012)
	3.4	<0.05	-	560	0.083	24	1200	4600	510	Kjolholt et al. (2012)
	12	<0.05	-	740	0.12	29	4500	17,000	280	Kjolholt et al. (2012)
	9.8	0.094	-	860	<0.05	3.8	3100	14,000	420	Kjolholt et al. (2012)
	3.5	<0.05	-	470	<0.05	19	930	3400	270	Kjolholt et al. (2012)
	10	0.063	-	500	0.089	17	2200	7600	150	Kjolholt et al. (2012)
	8.8	<0.05	-	390	<0.05	1.6	1300	6100	160	Kjolholt et al. (2012)
MV Ficaria Seaways	1.4	0.1	5.6	190	<0.05	26.4	43	164	324	Hansen et al. (2012)
MV Fjordshell	<0.1	0.05	<1	42	<0.1	5	33	35	6	Buhaug et al. (2006);
	<0.1	0.08	<1	15.3	<0.1	0.6	10.4	23	15	Lange et al. (2015)
MS Zaandam	81	-	22	18	-	0.4	20	-	-	HA & H-K (2010); USEPA (2011)
Pride of Kent	-	-	-	32-129	-	18-34	34	-	138-537[1]	Hufnagl (2005); USEPA (2011)
MV Magnolia Seaways	1.4	<0.29	1.9	21	-	0.61	41	162	6.7	Koski et al. (2017)
Unknown bulk carrier	0.03	0.03	11.6	3	-	1.39	18	39	17.3	Koyama et al. (2018)
Unknown bulk carrier	0.018	0.042	14.8	9.37	-	0.584	10.6	9.9	31.7	Koyama et al. (2018)
Unknown bulk carrier	1.02	0.035	22.8	8.12	-	1.755	17.9	58	48.3	Koyama et al. (2018)
A, RoRo/RoPax	<10	<2	<1.5-30	<10-140	<0.2	<1-120	<10-240	30-860	<10-2,000	EGCSA (2018)
B, RoRo/RoPax	<10	<2	<10	<10-120	<0.2	<10	20-50	70-140	<20-130	EGCSA (2018)
C, RoRo container	<10	<2	40	<10	-	<10	50	70	310	EGCSA (2018)
D, Tanker	<10	<2	<10-10	<10-20	<0.2	<10	20-60	70-240	<20-20	EGCSA (2018)
E, Cruise	<5	<0.2	<1.5-2	9-59	-	<1-8	35-120	56-240	<10-130	EGCSA (2018)
F, Vehicle Carrier	<10	<2	40	20	<0.2	<10	10	30	30	EGCSA (2018)
MS Zaandam	81	-	12	15	-	0.4	12	-	-	USEPA (2011)
Stena Britannica	20	<0.2	9	150	0.0052	<6	830	9,800	<70	Magnuson et al. (2018)
Stena Transporter	9.8	<0.5	22	32	0.0014	0.16	4400	13,000	46	Magnuson et al. (2018)
Stena Forerunner	2.4	<0.5	31	14	0.0065	0.63	32	84	82	Magnuson et al. (2018)
Ships 1,2,3,4,5	1-6.9	0.01-0.07	-	1.7-19.7	-	0.09-2.22	5.5-74.7	12.2-314	2.2-134	BSH (2018)
Ships 1,2,4,5	7-26.7	0.03-0.41	-	9.0-66.2	-	0.55-3.97	310-6,290	3,247-10,636	24.7-301	BSH (2018)
Unknown ship 1	<20-84	<1-<2	<2-<20	790-1900	<0.2	<10-<20	390-4800	5500-7000	140-420	Teuchies et al. (2020)
Unknown ship 1	<10-21	<1-<2	<10-160	<20-100	<0.2	<10-17	<10-180	220-970	<40-190	Teuchies et al. (2020)
Unknown ship 2	6.3-8.7	<0.1-<10	6.5-17	9.4-15	-	2.1-8.3	<10-50	30-130	<10-270	Teuchies et al. (2020)

[1] Zn levels are thought to be unreliable and due to contamination during sampling.

Table A-3: Hydrocarbon concentrations (µg/L) in scrubber washwater discharges.

Ship name	Total PAHs (16 USEPA)	Napthalene	Benzo[a]-pyrene	TPH	Reference
MV Ficaria: Open-loop, salt water	0.96	0.48	-	110-330	Kjølholt et al. (2012)
	1.1	0.51	-	140	Kjølholt et al. (2012)
	1.8	0.52	-	330	Kjølholt et al. (2012)
	1.6	0.57	-	200	Kjølholt et al. (2012)
Closed-loop, freshwater	9.2	0.71	-	500	Kjølholt et al. (2012)
	16	0.71	-	4500	Kjølholt et al. (2012)
	3.8	0.32	-	11,000	Kjølholt et al. (2012)
	16	0.75	-	5400	Kjølholt et al. (2012)
	30	0.82	-	29,000	Kjølholt et al. (2012)
	24	0.49	-	21,000	Kjølholt et al. (2012)
MV Fjordshell	<0.1	-	-	-	Markus & Helfst (2015)
MS Zaandam	1.3[1]	-	-	-	USEPA (2011)
Pride of Kent	11.9-20.4[2]	-	-	-	Hufnagl (2005); USEPA (2011)
MT Suula	14[1]	-	-	<1000	USEPA (2011)
MV Magnolia Seaways	<0.05	<0.005	-	-	Koski et al. (2017)
Vessel A, RoRo/RoPax	1.3-24	0.32-14	0.02-0.15	-	EGCSA (2018)
Vessel B, RoRo/RoPax	0.5-12.7	0.34-3.5	<0.01-0.09	-	EGCSA (2018)
Vessel C, RoRo container	12.7	10	0.88	-	EGCSA (2018)
Vessel D, Tanker	0.6-5.5	0.2-3.7	<0.01	-	EGCSA (2018)
Vessel E, Cruise	15	0.48	<0.01	-	EGCSA (2018)
Vessel F, Vehicle Carrier	9.1-12	1.2-6.9	1.2	-	EGCSA (2018)
Stena Britannica	21.9	4.4	0.21	7,106	Magnuson et al. (2018)
Stena Transporter	16	4.8	-	1,960	Magnuson et al. (2018)
Stena Forerunner	13.5	7.5	-	388	Magnuson et al. (2018)
Ships 1,2,3,4,5	1.6-18.6	0.6-9.5	-	110-2,400[3]	BSH (2018)
Ships 1,2,4,5	11.8-54.4	0.1-3.9	-	5,260[3]	BSH (2018)
Unknown ship 1	13-18	6.4	<0.1	786-1,060	Teuchies et al. (2020)
Unknown ship 1	2.1-2.2	1-1.2	<0.1	<100	Teuchies et al. (2020)
Unknown ship 2	2-<6.1	0.42-1.8	0.019-0.031	1,200-2,300	Teuchies et al. (2020)

[1] PAHphe determined from sample collected. On-line measurements unreliable.

[2] Determined in undiluted wash water prior to dilution with seawater. Phenanthrene 5.1-8.2 µg/L.

[3] Reported as The Hydrocarbon Oil Index (HOI), the total amount of compounds which can be extracted from the sample with a non-polar solvent having a boiling point between 39°C and 69°C. Result should be similar to TPH.

Appendix B Example of information on a scrubber from IMO GISIS website

Merchant Shipping Directorate

Transport Malta

INTERNATIONAL CONVENTION FOR THE PREVENTION OF POLLUTION FROM SHIPS

Equivalent Compliance Method under Regulation 4.1

MARPOL Annex VI

The Merchant Shipping Directorate has accepted the equivalent arrangement under the provisions of Regulation 4 of Annex VI of the International Convention for the Prevention of Pollution from Ships on the following vessel. This vessel is a passenger ship equipped with diesel-electric propulsion.

Name of Ship	IMO Number	Keel Laying Date
CELEBRITY SOLSTICE	9362530	09 SEPTEMBER 2005

In accordance with the provision of regulation 4.1, this is to certify that the Malta Administration has accepted the installation of the WARTSILA MOSS AS Inline 15N06F/1-SC200F, 15N06F/2-SC230F & additional Inline 15N01A/1-2850/SC200 A Hybrid System Exhaust Gas Cleaning Systems (EGCS serial No.111, 112 & 169) as an equivalent arrangement to the use of Low Sulphur Fuel Oil (LSFO) as specified under regulation 14.4.3 of MARPOL Annex VI.

The first two exhaust gas cleaning systems are connected to WARTSILA 16V46 main engines No.1 and No.2 (PAAE042139 & PAAE042138) located in the forward engine room are currently certified to operate only in the open loop or closed loop mode, whilst the second exhaust gas cleaning system being connected to WARTSILA 16V46 No.3 and No.4 (PAAE042137 & PAAE042136) is located in the aft engine room is certified to operate in hybrid (open and closed loop) mode.

The two engines No.3 and 4 located in the aft engine room shares a common scrubbing tower and a by-pass arrangement allowing for both above mentioned engines to be scrubbed independently but not simultaneously.

These EGCS systems have been certified as complying with Scheme B (Continuous Emissions Monitoring) as specified in IMO Resolution MEPC.259 (68).

Fuel Oil Combustion Units connected to EGC units

EGC units (15N06F/1-SC200F Serial No.111 & 1515N06F/2-SC230F Serial No.112)							
Qty	Make	Type	Serial no.	Power	Installed	Description	Application
1	Wärtsilä	16V46	PAAE042139	16800kW	Fwd engine room	4 stroke	Main engine
1	Wärtsilä	16V46	PAAE042138	16800kW	Fwd engine room	4 stroke	Main engine

Transport Malta is the Authority for Transport in Malta set up by ACT XV of 2009

Merchant Shipping Directorate

Transport Malta

EGC unit (Inline 2850/SC200 A Serial No.169)							
Qty	Make	Type	Serial no.	Power	Installed	Description	Application
1	Wärtsilä	16V46	PAAE042137 PAAE042136	16800kW	Aft engine room	4 stroke	Main engine

Such an EGCS arrangement has been endorsed on the vessel's IAPP certificate.

In terms of regulation 4.2 of the aforementioned Convention, the government of Malta is submitting the enclosed statement concerning the acceptance of the emission abatement method for the subject vessel in the above statement.

This submission is being made in order to inform the Parties of the changes carried out to the above mentioned EGC systems.

This submission supersedes the previous notification letters dated 9 November 2017 and 8 January 2018.

Issued at Valletta Malta on the 10 May 2018

Ivan Sammut
Registrar General of
Shipping and Seamen

Merchant Shipping Directorate is ISO 9001:2008 certified

Transport Malta is the Authority for Transport in Malta set up by ACT XV of 2009